US011149761B2

(12) United States Patent

Ito et al.

(10) **Patent No.: US 11,149,761 B2**

(45) **Date of Patent: Oct. 19, 2021**

(54) **FLUID ACTUATOR**

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(21) Appl. No.: **16/936,082**

(22) Filed: **Jul. 22, 2020**

(65) **Prior Publication Data**

US 2021/0040962 A1 Feb. 11, 2021

(30) **Foreign Application Priority Data**

Aug. 7, 2019 (JP) JP2019-145247

(51) **Int. Cl.**

F15B 15/14 (2006.01)

F15B 13/04 (2006.01)

(52) **U.S. Cl.**

CPC ***F15B 15/1404*** (2013.01); ***F15B 13/04*** (2013.01); ***F15B 15/1428*** (2013.01)

(58) **Field of Classification Search**

CPC F15B 15/1428; F15B 15/1404

See application file for complete search history.

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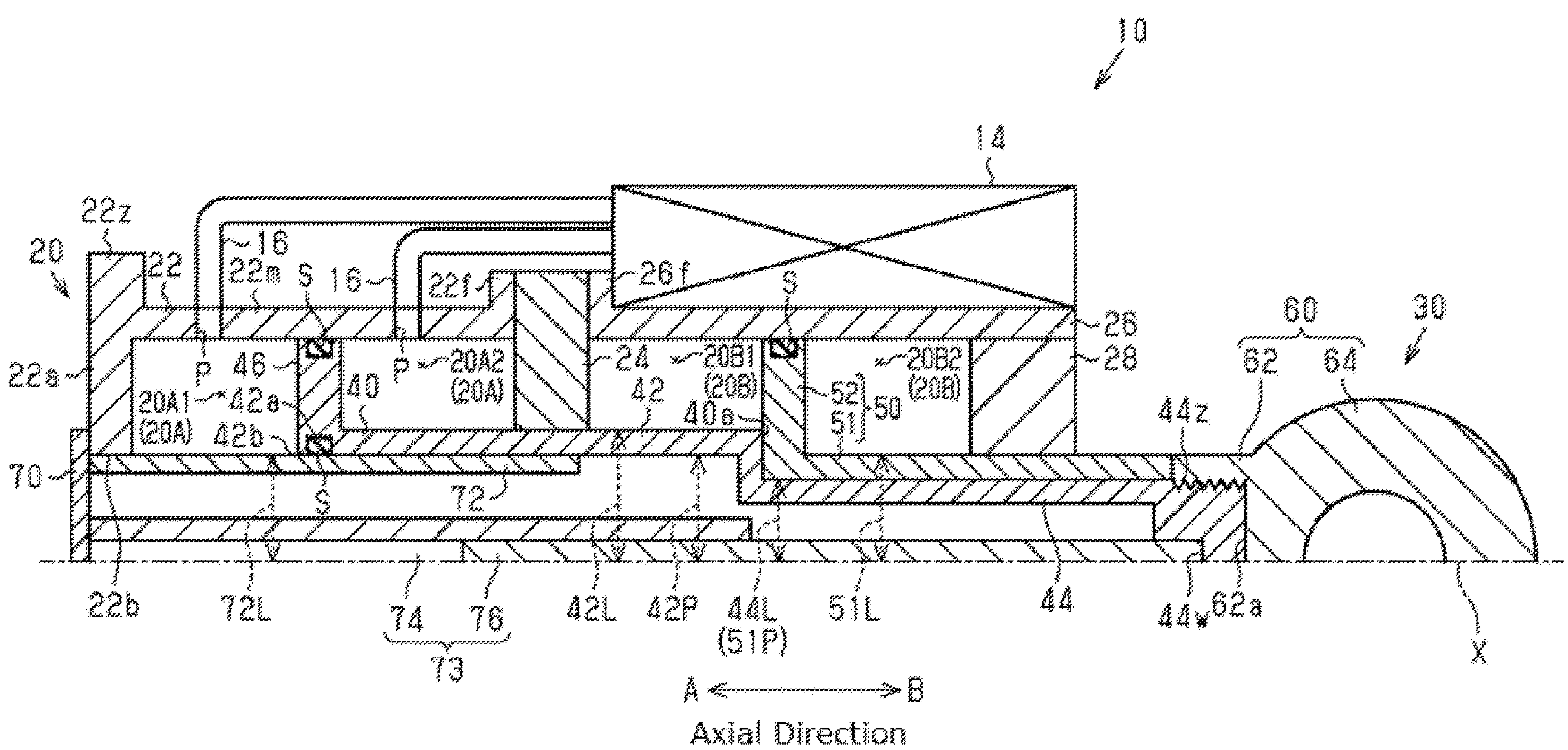
(57) **ABSTRACT**

One object is to reduce a weight of a fluid actuator. The fluid actuator includes: a cylinder having an inner space and a first mounting portion, the inner space being partitioned into a first fluid chamber and a second fluid chamber, the first mounting portion being disposed on an end portion of the cylinder on an axial direction A side; and a piston rod configured to reciprocate in accordance with pressures in the fluid chambers. A wall portion defining the first fluid chamber in the cylinder is made of an iron-based alloy. A wall portion defining the second fluid chamber in the cylinder is made of an aluminum alloy. The piston rod is made of an iron-based alloy.

5 Claims, 11 Drawing Sheets



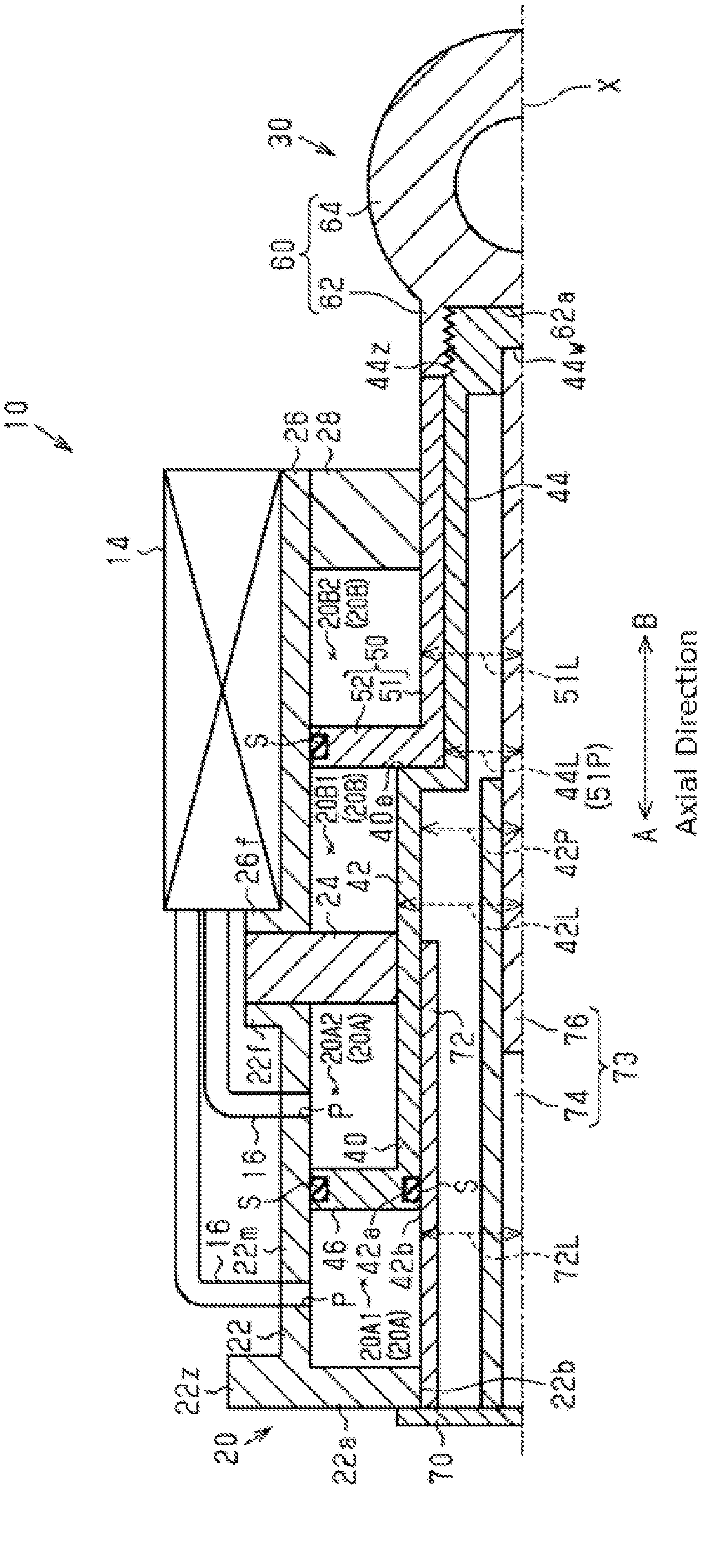

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Fig. 1

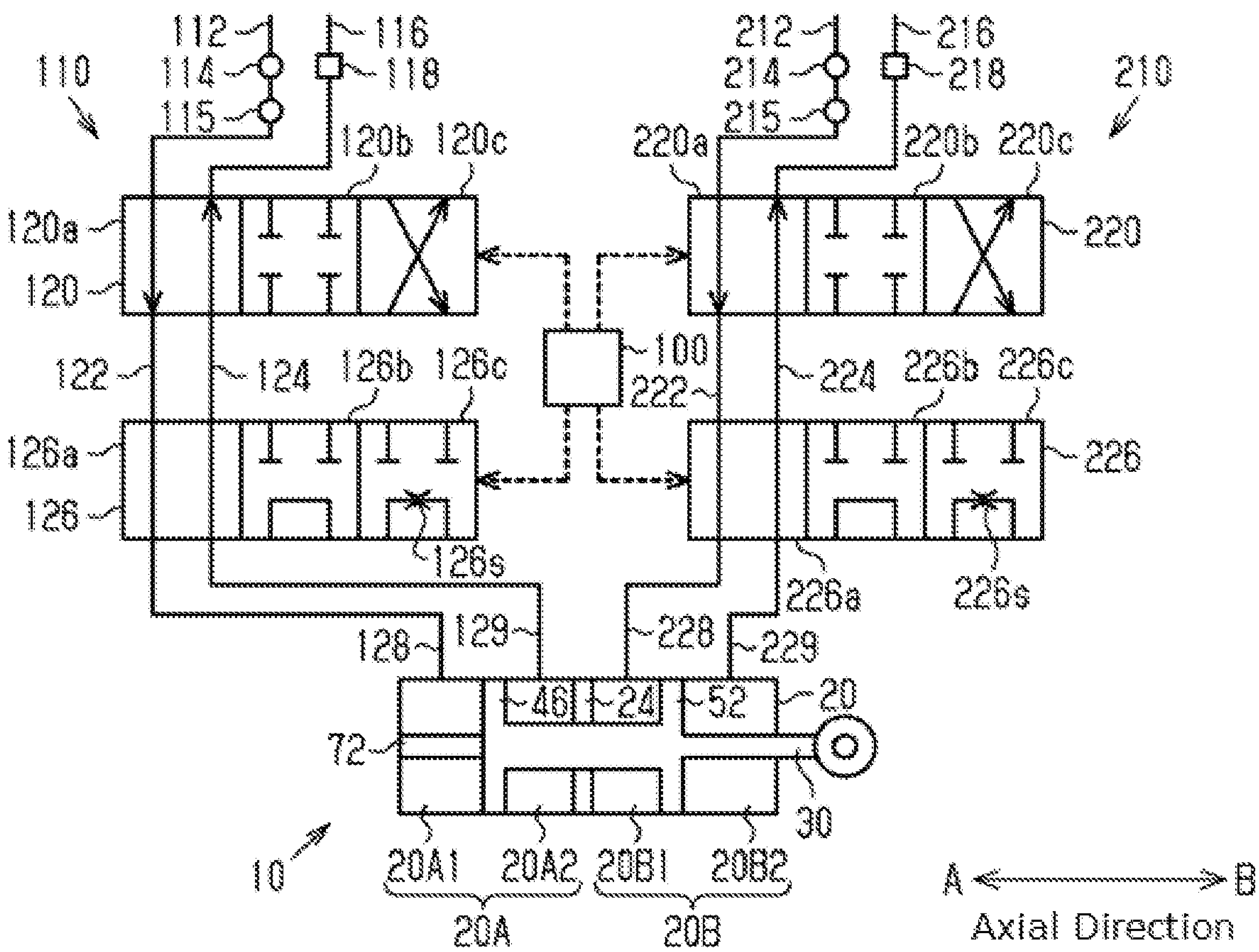
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Fig. 2

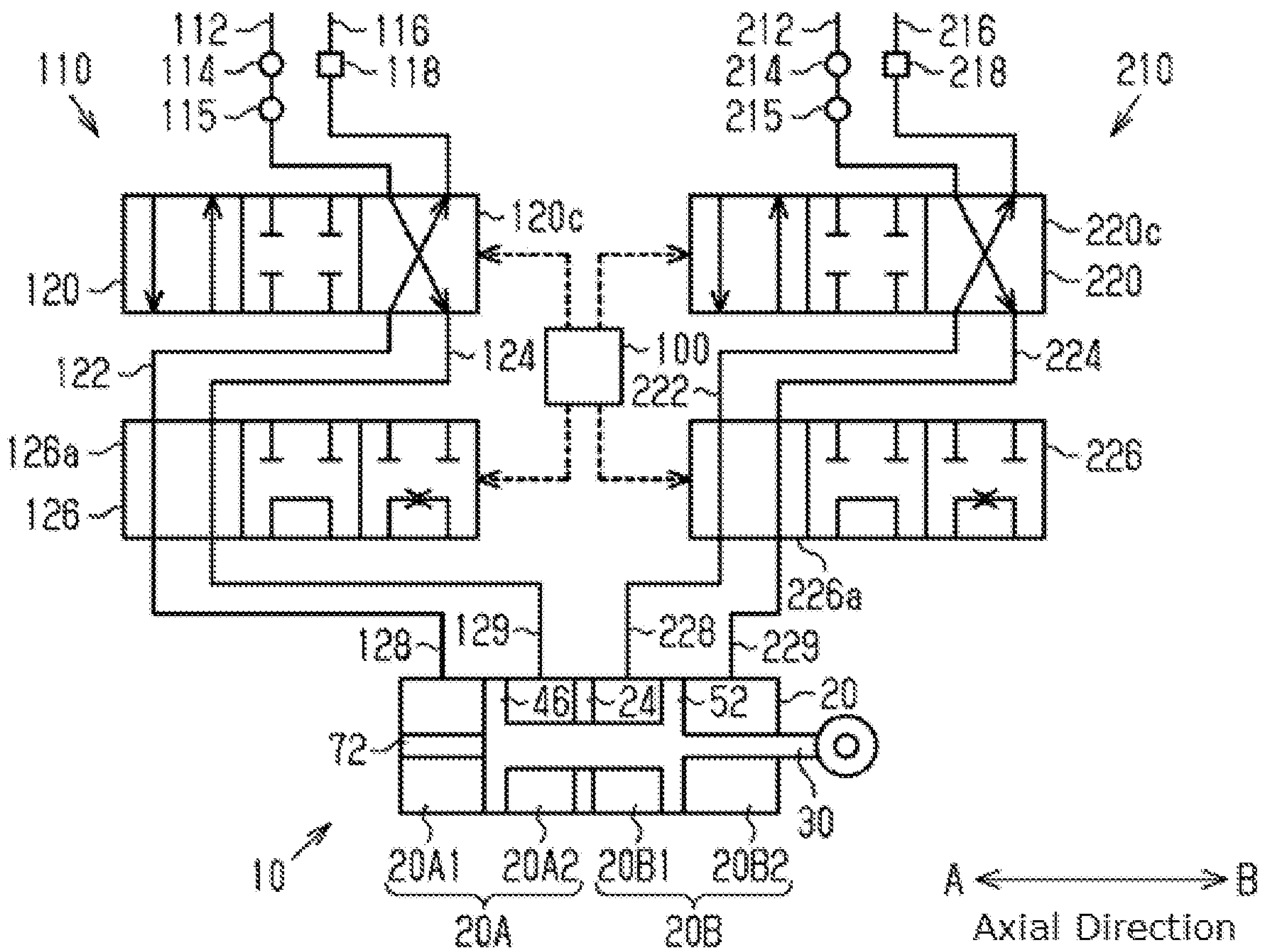
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Fig. 3

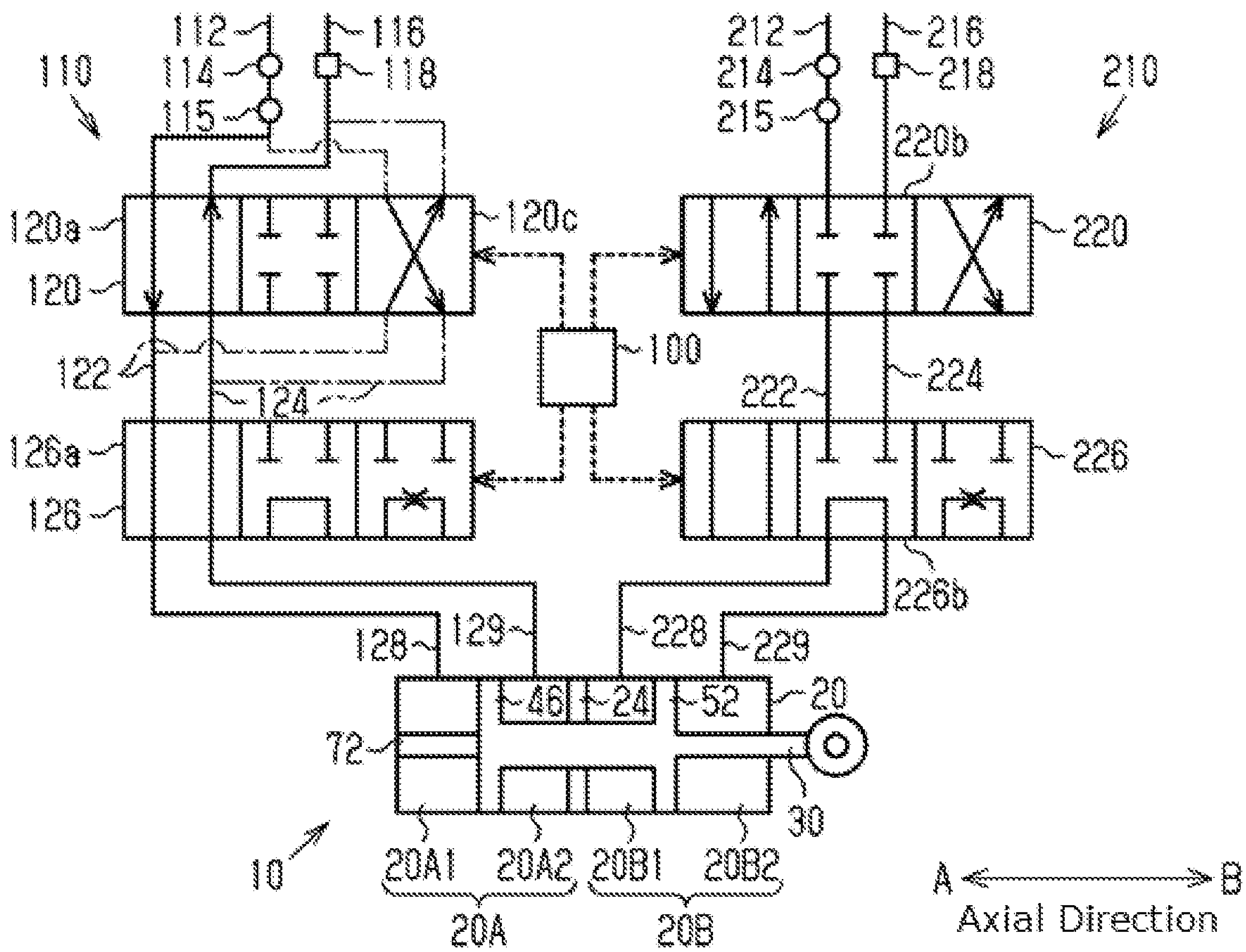
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Fig. 4

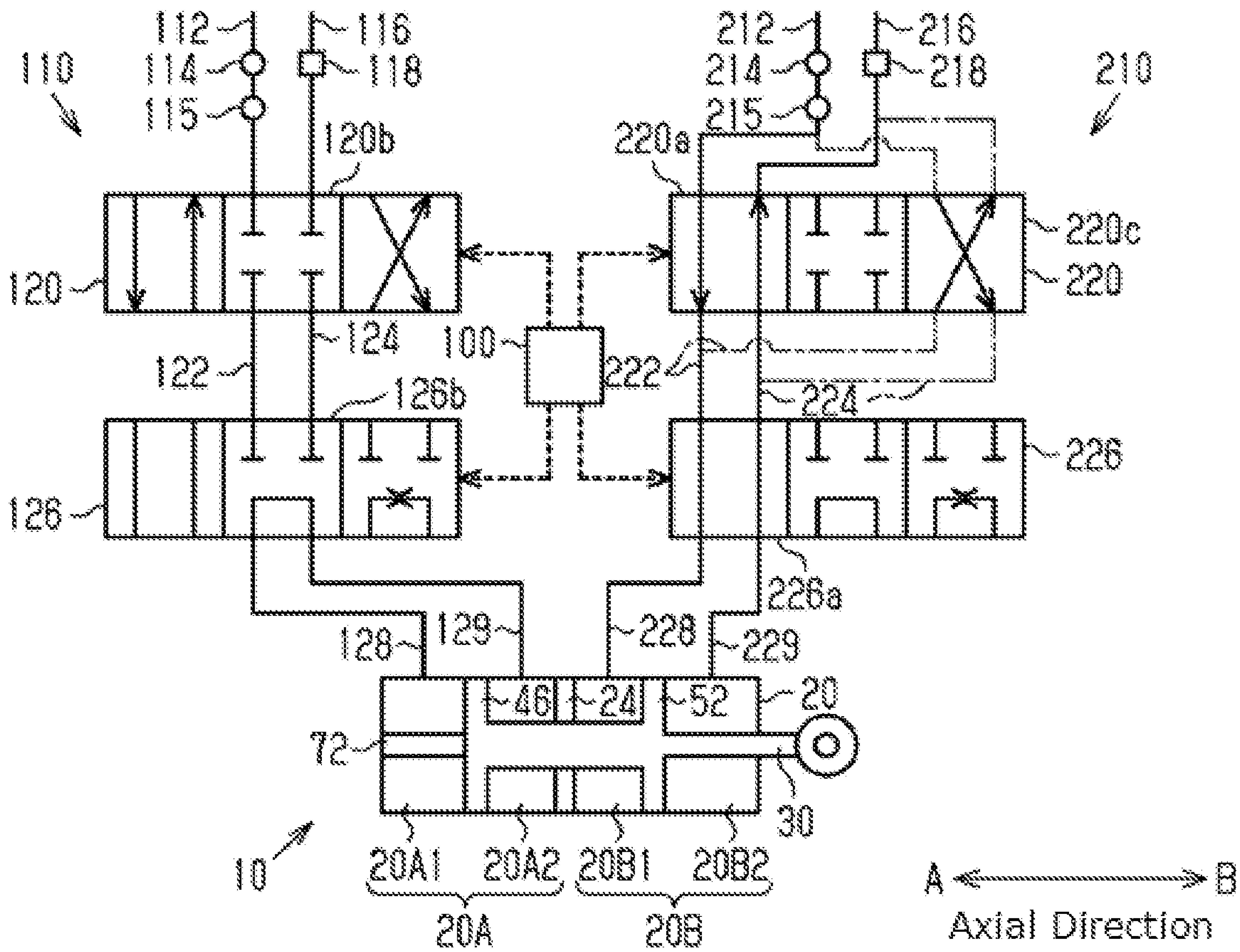
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Fig. 5

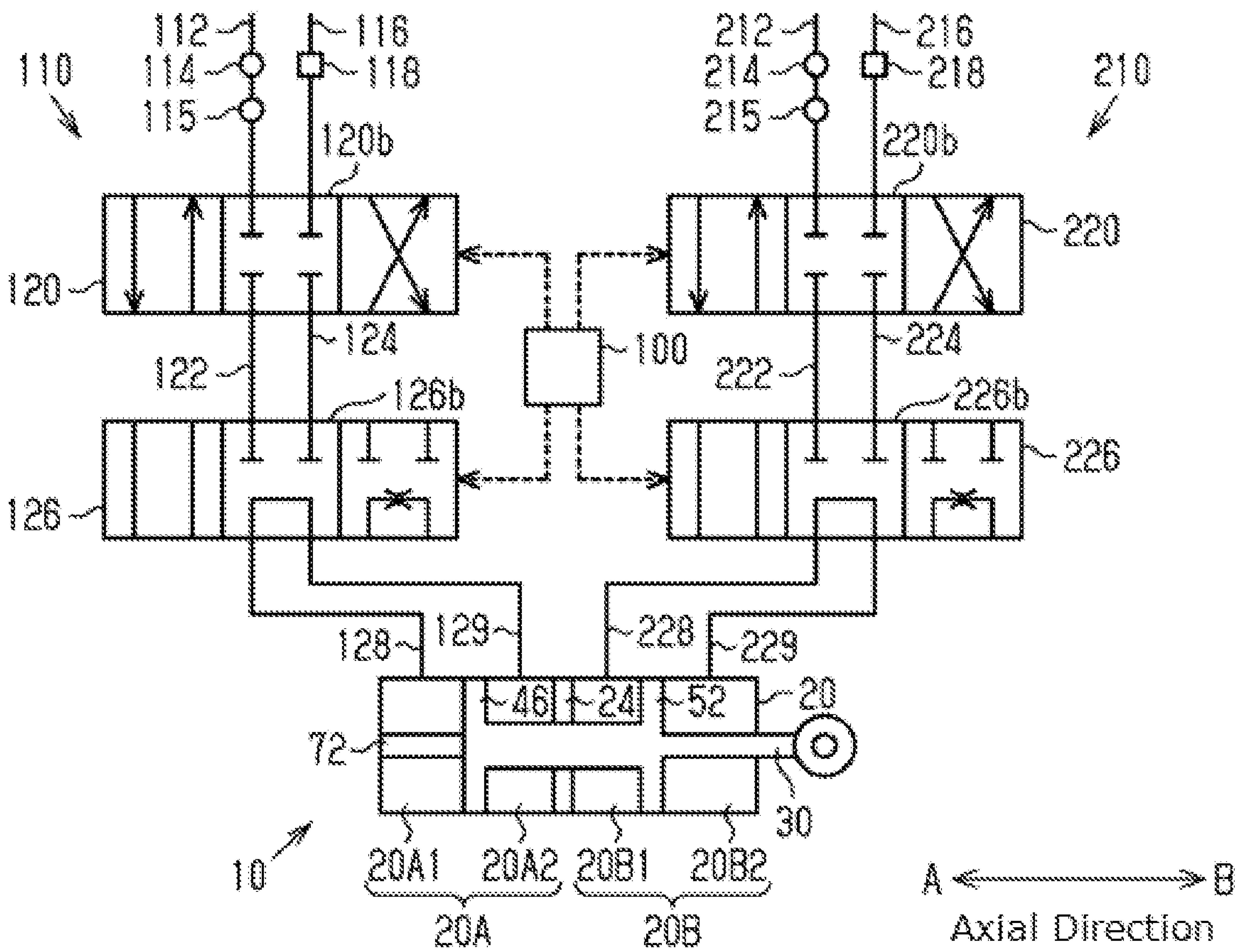
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Fig. 6

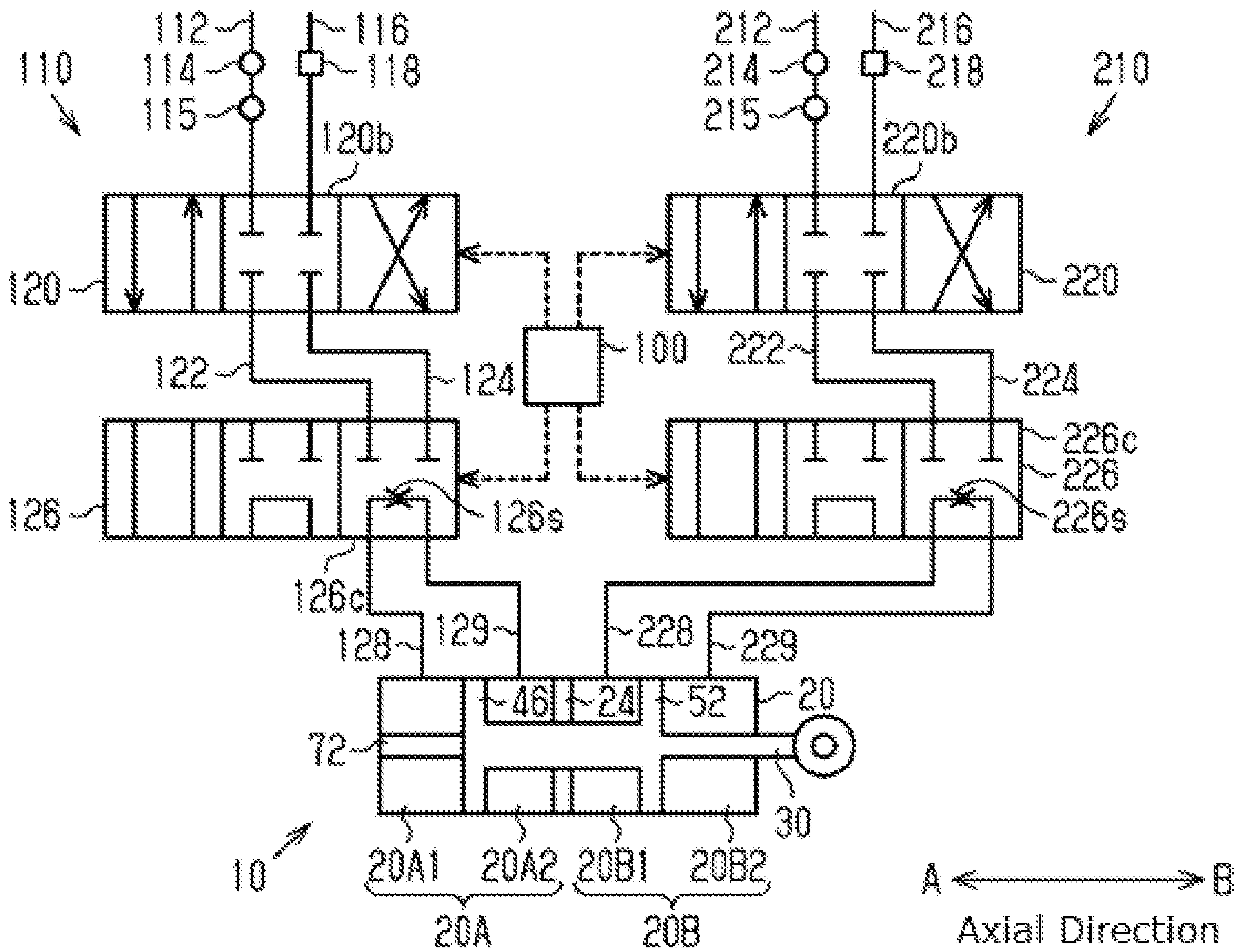
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Fig. 7

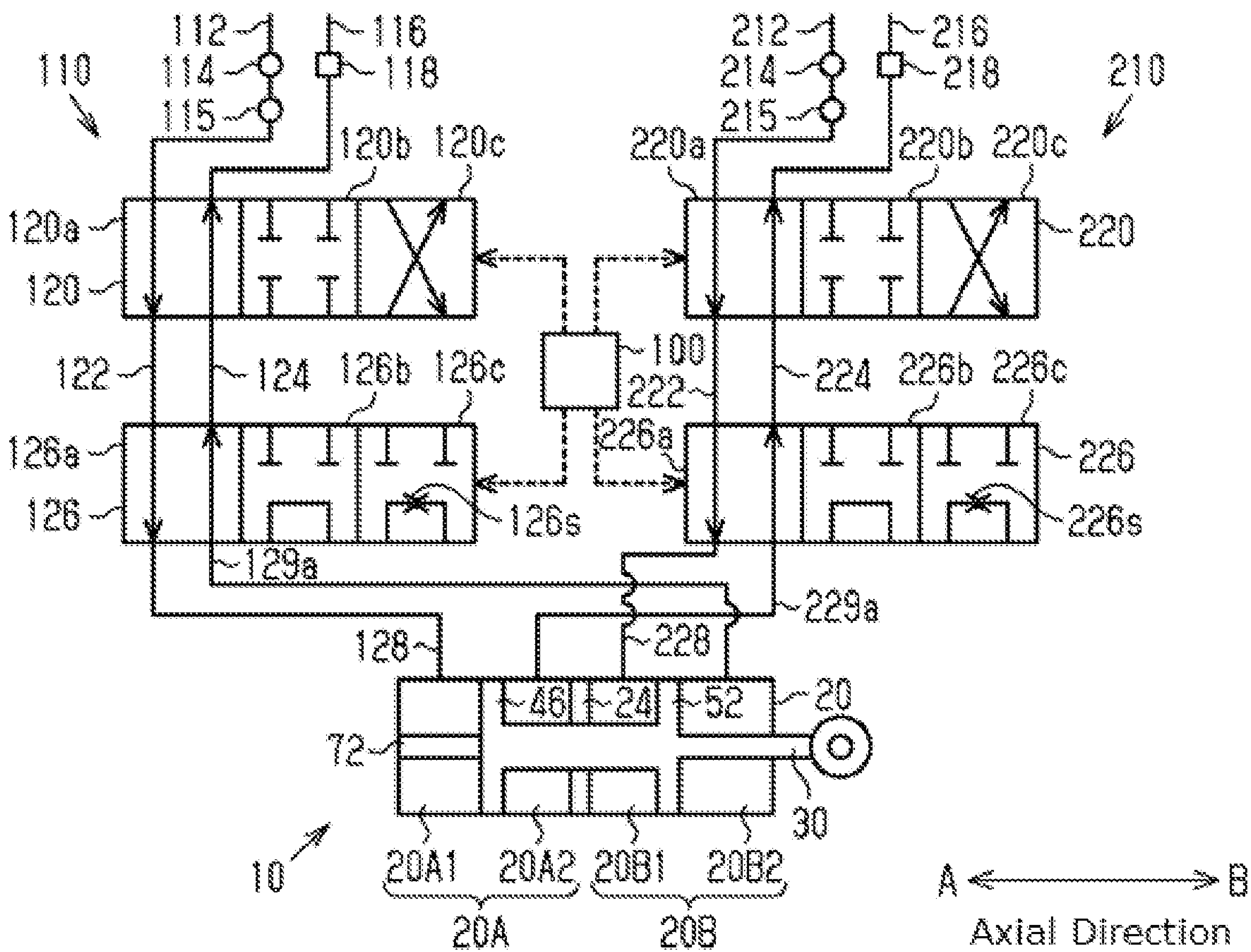
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Fig. 8

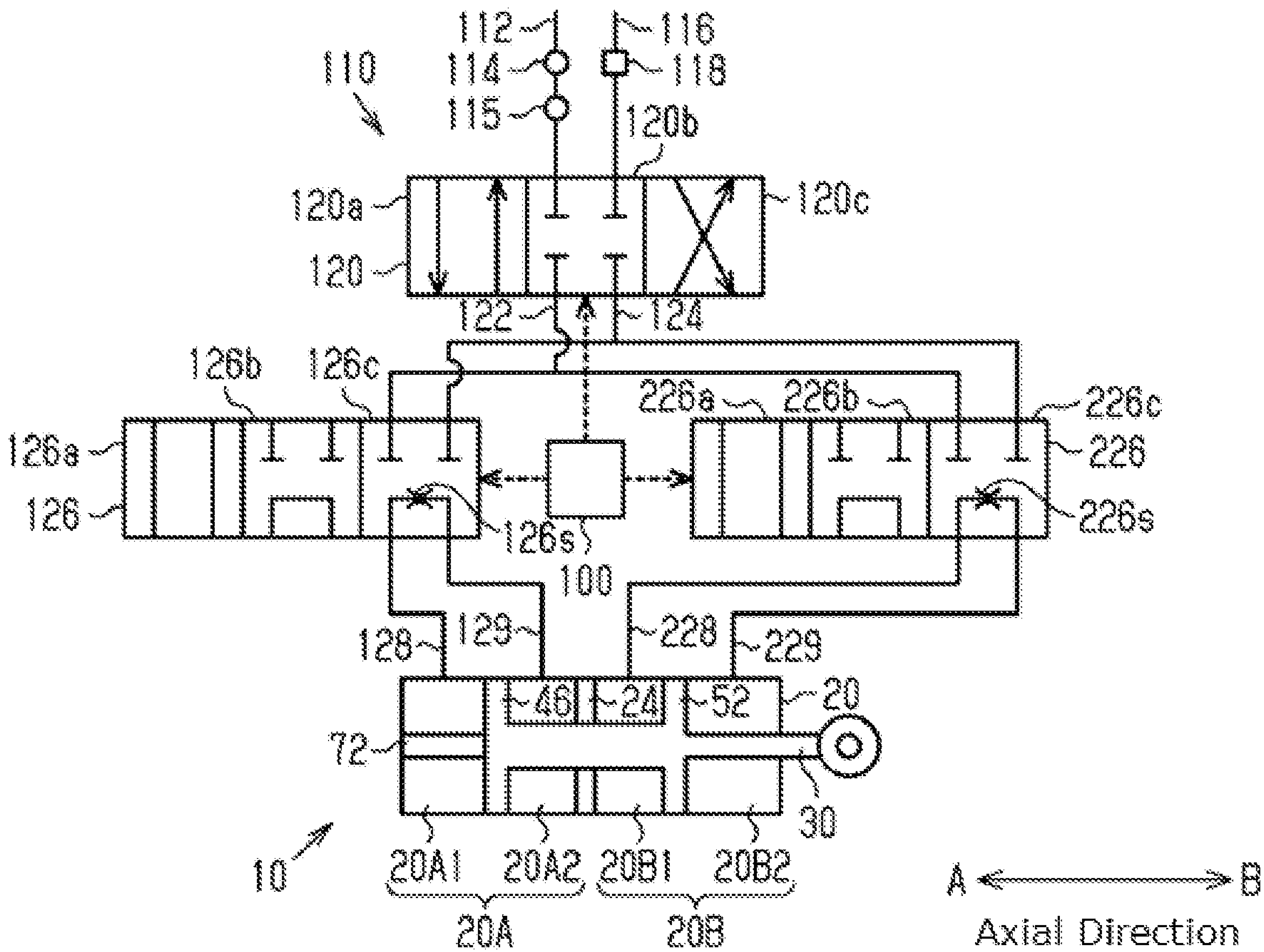

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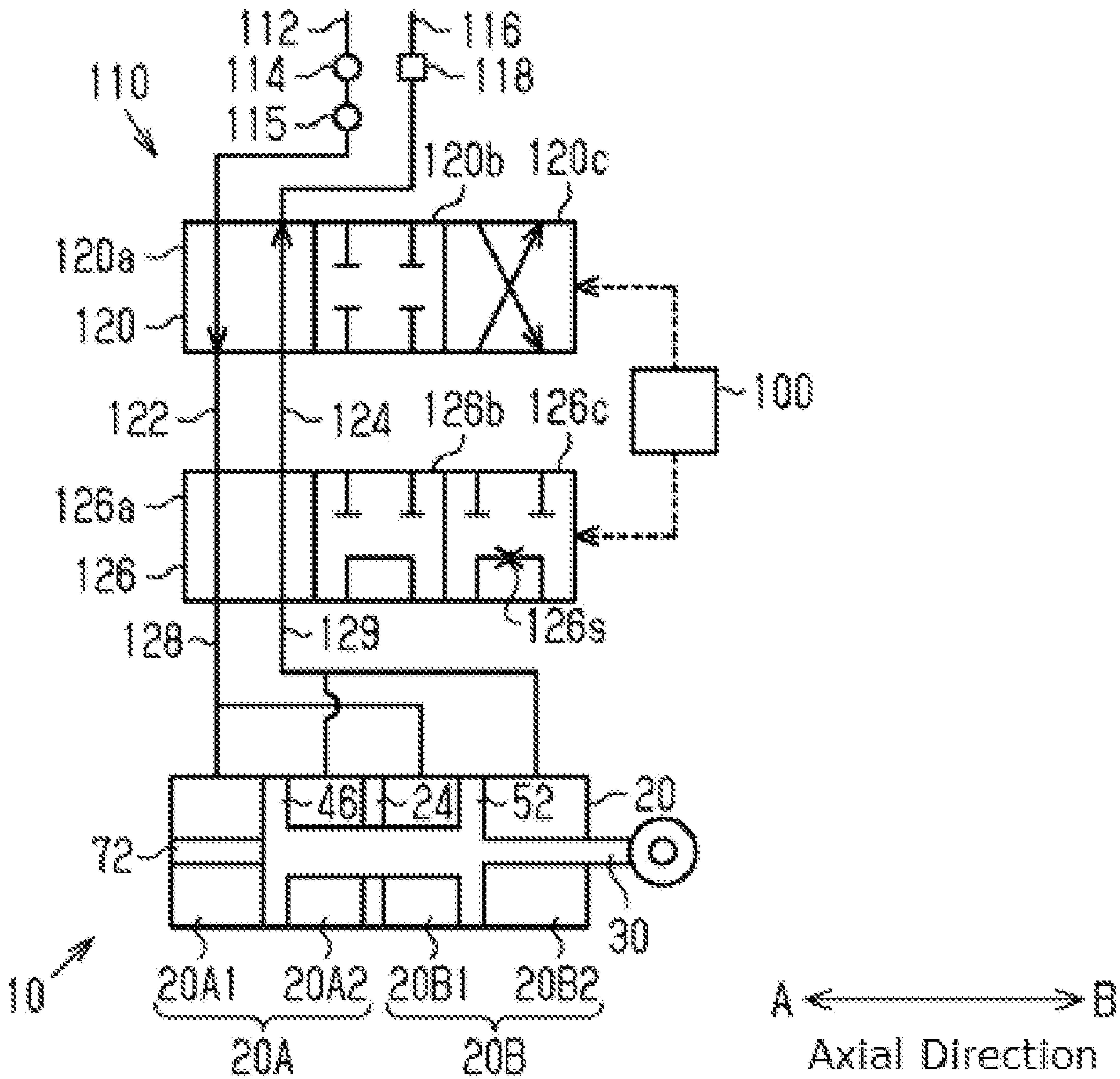
Fig. 9



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Axial Direction

Fig. 10

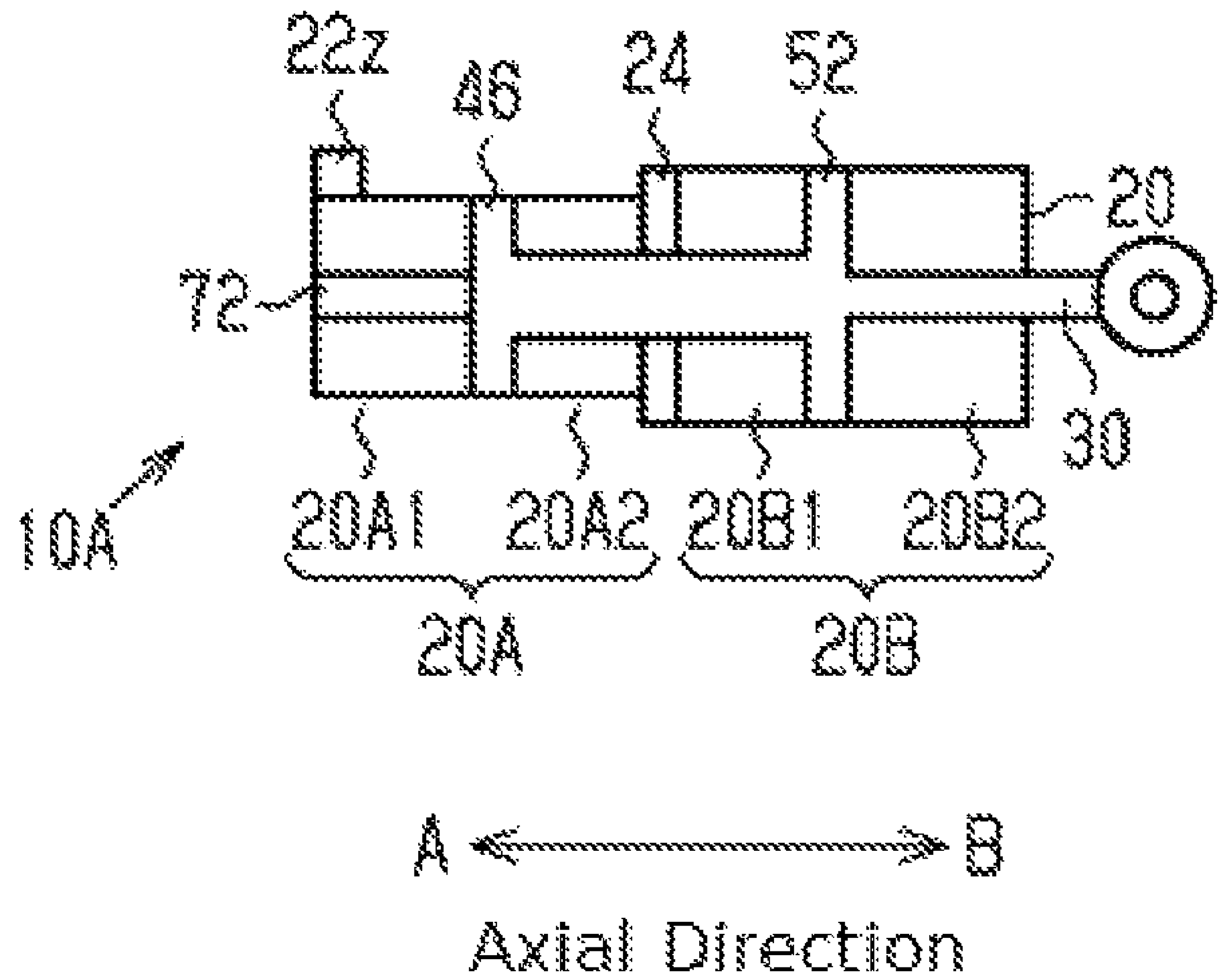
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Fig. 11

FLUID ACTUATOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based on and claims the benefit of priority from Japanese Patent Application Serial No. 2019-145247 (filed on Aug. 7, 2019), the contents of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

The present invention relates to a fluid actuator.

BACKGROUND

In the fluid actuator disclosed in Japanese Patent No. 3652642 ("the '642 Patent"), a fluid chamber is defined within a cylinder. The cylinder contains a piston that partitions the fluid chamber into two chambers. Variation of the pressure of the fluid fed into the fluid chamber causes the piston to reciprocate, and an object mounted to the piston is moved in accordance with the reciprocation of the piston.

In actuators such as disclosed in the '642 Patent, the cylinder and other members are made of a highly rigid material such that they can withstand a pressure of the fluid fed into the fluid chamber and external impacts. However, in general, a material having a certain degree of rigidity, such as stainless steels, has a large weight. Therefore, it is difficult to reduce the weight of fluid actuators.

SUMMARY

The present invention addresses such circumstances, and one object thereof is to provide a lightweight fluid actuator.

A fluid actuator for achieving the above object comprises: a cylinder having a columnar inner space and a mounting portion, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space, the mounting portion being disposed on an end portion of the cylinder on one axial direction side of the inner space and configured to be mounted to an external object; and a piston rod extending across the plurality of fluid chambers and having a piston partitioning each of the plurality of fluid chambers into two chambers, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the plurality of fluid chambers, wherein in the cylinder, a wall portion partitioning one of the plurality of fluid chambers positioned at an end on the one axial direction side is made of an iron-based alloy, and a radial wall portion partitioning another of the plurality of fluid chambers positioned on the other axial direction side beyond the one of the plurality of fluid chambers positioned at the end on the one axial direction side is made of an aluminum alloy, and wherein the piston rod is made of an iron-based alloy.

The cylinder is basically required to have rigidity, for example, in the vicinity of the mounting portion. In addition, in the cylinder, a pressure produced by movement of the piston tends to act on the wall portions positioned on the axis of the cylinder such as the wall portion partitioning adjacent fluid chambers. Therefore, a high rigidity is required in these wall portions. On the other hand, the wall portions defining the radially outer side of the fluid chambers receive less pressure produced by the movement of the piston. Therefore, the wall portions defining the radially outer side of the fluid chambers are not required to have as high a rigidity as

the portions in the vicinity of the coupling portion. Such wall portions can be made of an aluminum alloy to reduce the weight of the cylinder. As a result, the weight of the fluid actuator can be reduced.

It is possible that the fluid actuator further includes a manifold mounted to the cylinder and containing a hydraulic circuit of a fluid to be fed to and discharged from the fluid chambers, and the manifold is made of an aluminum alloy. Since the manifold mounted to the cylinder is made of an aluminum alloy, the weight of the fluid actuator can be reduced.

In the fluid actuator, it is possible that the fluid circuit and the plurality of fluid chambers are connected via a pipe extending from the manifold to the cylinder.

Since the manifold and the cylinder are connected via a pipe, the manifold does not need to extend to the vicinity of the fluid chambers in the cylinder, and thus the manifold can be downsized.

In the fluid actuator, supposing that the two chambers of each of the fluid chambers partitioned by the piston include a first partition chamber on the one axial direction side and a second partition chamber on the other axial direction side, a cross-sectional area orthogonal to the axial direction related to the first partition chamber may be different from a cross-sectional area orthogonal to the axial direction related to the second partition chamber.

The piston rod may move in accordance with the movement of an external object mounted to the piston rod. At a moment when the piston rod moves, the piston rod will move with substantially no fluid flowing into or out of the first partition chamber and the second partition chamber. In the above configuration, the first partition chamber and the second partition chamber have different cross-sectional areas. Therefore, when the piston is positioned around the axial middle of a fluid chamber, the first partition chamber and the second partition chamber have different volumes. In this configuration, when substantially no fluid flows into or out of the first partition chamber and the second partition chamber, a force acts on the piston in the direction described as follows. The force acts from the first or second partition chamber having the larger volume produced by the larger cross-sectional area toward the other partition chamber having the smaller volume produced by the smaller cross-sectional area. For example, when in some of the plurality of fluid chambers, the first partition chamber has the larger orthogonal cross-sectional area, while in the other fluid chambers, the second partition chamber has the larger orthogonal cross-sectional area, and these fluid chambers are arranged randomly, the piston rod receives a force acting toward the one axial direction side of the cylinder and a force acting toward the other axial direction side. The piston rod receiving these forces is inhibited from moving in the axial direction. This is favorable in suppressing the movement of the piston rod.

In the fluid actuator, there are two fluid chambers provided. In one of the two fluid chambers, the partition chamber having the larger cross-sectional area among the two partition chambers may be positioned on the one axial direction side, while in the other fluid chamber, the partition chamber having the larger cross-sectional area among the two partition chambers may be positioned on the other axial direction side.

For example, in the fluid chamber on the one axial direction side of the cylinder, the first partition chamber has a larger cross-sectional area than the second partition chamber, while in the other fluid chamber, the second partition chamber has a larger cross-sectional area than the first partition chamber. In this configuration, at a moment when the piston rod moves in accordance with the movement of an external object mounted to the piston rod, or when substantially no fluid flows into or out of the first partition chamber and the second partition chamber, the piston supposed to be positioned around the axial middle of the fluid chamber receives forces acting thereon in the directions described as follows. In the fluid chamber on the one axial direction side, a force acts from the first partition chamber toward the second partition chamber, or toward the other axial direction side of the cylinder. In the fluid chamber on the other axial direction side, a force acts from the second partition chamber toward the first partition chamber, or toward the one axial direction side of the cylinder. In other words, with respect to the axial direction of the cylinder, the piston rod receives the forces acting thereon from both its sides toward the middle of the cylinder, and therefore, the piston rod is easily retained in the position around the middle.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a longitudinal section of a fluid actuator.

FIG. **2** is a schematic diagram showing a first switching pattern in a fluid actuator system.

FIG. **3** is a schematic diagram showing the first switching pattern in the fluid actuator system.

FIG. **4** is a schematic diagram showing a second switching pattern in the fluid actuator system.

FIG. **5** is a schematic diagram showing a third switching pattern in the fluid actuator system.

FIG. **6** is a schematic diagram showing a fourth switching pattern in the fluid actuator system.

FIG. **7** is a schematic diagram showing a fifth switching pattern in the fluid actuator system.

FIG. **8** is a schematic diagram showing a modification of a hydraulic circuit.

FIG. **9** is a schematic diagram showing a modification of the hydraulic circuit.

FIG. **10** is a schematic diagram showing a modification of the hydraulic circuit.

FIG. **11** is a schematic diagram showing a modification of the fluid actuator.

DESCRIPTION OF THE EMBODIMENTS

An embodiment of a fluid actuator system including a fluid actuator is hereinafter described. A fluid actuator system is used for operation of a flap of an aircraft.

First, a fluid actuator is described. As shown in FIG. **1**, a cylinder **20** of a fluid actuator **10** includes a first cylinder unit **22**. A main body **22***m* of the first cylinder unit **22** has a cylindrical shape. The central axis X of the main body **22***m* of the first cylinder unit **22** is the central axis of the cylinder **20**. The main body **22***m* of the first cylinder unit **22** is closed at an end thereof on the axial direction A side with an end wall **22***a*. The end wall **22***a* is penetrated by a bottom through-hole **22***b* having a circular shape in plan view. The central axis of the bottom through-hole **22***b* is aligned with the central axis X of the main body **22***m* of the first cylinder unit **22**. A first mounting portion **22***z* projects outward from the outer peripheral surface of the main body **22***m* of the first cylinder unit **22**. The first mounting portion **22***z* is used to mount an external object to the cylinder **20**. The first mounting portion **22***z* has a plate-like shape. The first mounting portion **22***z* is positioned on the end portion of the main body **22***m* of the first cylinder unit **22** on the axial direction A side. Although not shown, the first mounting portion **22***z* has a boss or the like to be penetrated by a bolt for mounting the fluid actuator **10** to an external object. In this embodiment, the first cylinder unit **22** is mounted to an airframe of an aircraft via the first mounting portion **22***z*. In the axial direction, the side where the first mounting portion **22***z* is positioned is "the axial direction A side" corresponding to "one axial direction side," and the side opposite to the A side is "the axial direction B side" corresponding to "the other axial direction side."

A flange **22***f* projects outward from the outer peripheral surface of the main body **22***m* of the first cylinder unit **22**. The flange **22***f* is positioned at the end of the main body **22***m* of the first cylinder unit **22** on the axial direction B side. The flange **22***f* extends over the entire circumference of the main body **22***m* of the first cylinder unit **22**. The outer peripheral wall of the main body **22***m* of the first cylinder unit **22** is penetrated by two ports P. One of the two ports P is provided on the A side and the other on the B side of the axial middle of the main body **22***m* of the first cylinder unit **22**. The material of the first cylinder unit **22** is a stainless steel. Specifically, all the wall portions constituting the main body **22***m* of the first cylinder unit **22**, the end wall **22***a*, the first mounting portion **22***z*, and the flange **22***f* are made of a stainless steel, or an iron-based alloy.

A second cylinder unit **24**, which has an annular shape in plan view, is disposed on the end surface of the main body **22***m* of the first cylinder unit **22** on the axial direction B side. The second cylinder unit **24** is coaxial with the main body **22***m* of the first cylinder unit **22**. The inner diameter of the second cylinder unit **24** is smaller than that of the main body **22***m* of the first cylinder unit **22** and is larger than the diameter of the bottom through-hole **22***b* of the first cylinder unit **22**. The material of the second cylinder unit **24** is bronze.

A third cylinder unit **26**, which has a cylindrical shape, is disposed on the opposite side to the first cylinder unit **22** with respect to the second cylinder unit **24**. The third cylinder unit **26** is coaxial with the second cylinder unit **24**. The inner diameter and the outer diameter of the third cylinder unit **26** are equal to the inner diameter and the outer diameter of the main body **22***m* of the first cylinder unit **22**, respectively. A flange **26***f* projects outward from the outer peripheral surface of the third cylinder unit **26**. The flange **26***f* is positioned at the end of the third cylinder unit **26** on the axial direction A side. The flange **26***f* extends over the entire circumference of the end of the third cylinder unit **26**. The outer diameter of the flange **26***f* is equal to the outer diameter of the flange **22***f* of the first cylinder unit **22**. The flange **26***f* is integrally connected to the flange **22***f* of the first cylinder unit **22** and the second cylinder unit **24** with a bolt (not shown), in such an arrangement that the second cylinder unit **24** is interposed between the flange **26***f* and the flange **22***f* of the first cylinder unit **22**.

The outer peripheral wall of the third cylinder unit **26** is penetrated by two ports. One of the two ports is provided on the A side and the other on the B side of the axial middle of the third cylinder unit **26**. The ports of the third cylinder unit **26** are not shown in FIG. **1** since they are at positions different from the longitudinal section shown in FIG. **1**. The material of the third cylinder unit **26** is an aluminum alloy. Specifically, all the wall portions constituting the third cylinder unit **26** are made of an aluminum alloy.

A fourth cylinder unit **28**, which has an annular shape in plan view, is disposed on the end portion of the third cylinder unit **26** on the axial direction B side. The fourth cylinder unit **28** is disposed in the third cylinder unit **26**. The fourth cylinder unit **28** is coaxial with the third cylinder unit **26**.

The outer diameter of the fourth cylinder unit **28** is equal to the inner diameter of the third cylinder unit **26**. In other words, the fourth cylinder unit **28** closes the end of the third cylinder unit **26** on the axial direction B side. The material of the fourth cylinder unit **28** is a stainless steel.

As described above, the cylinder **20** is integrally assembled of the first cylinder unit **22**, the second cylinder unit **24**, the third cylinder unit **26**, and the fourth cylinder unit **28** into a shape of a cylinder with closed opposite ends as a whole. In other words, the cylinder **20** has a columnar inner space. The bottom portion of the cylinder **20** on the axial direction A side is constituted by the end wall **22***a* of the first cylinder unit **22**, and the bottom portion of the cylinder **20** on the axial direction B side is constituted by the fourth cylinder unit **28**. The inner space of the cylinder **20** is partitioned into two chambers arranged in the axial direction by the second cylinder unit **24** as a boundary. In other words, the cylinder **20** contains a first fluid chamber **20**A and a second fluid chamber **20**B defined therein and arranged in the axial direction thereof, the first fluid chamber **20**A is positioned on the axial direction A side, and the second fluid chamber **20**B is positioned on the axial direction B side.

On the outer peripheral surface of the cylinder **20**, there is mounted a manifold **14** containing a circuit (hereinafter referred to as "the hydraulic circuit") of a hydraulic fluid fed into and discharged from the first fluid chamber **20**A and the second fluid chamber **20**B. The manifold **14** as a whole has a rectangular parallelepiped shape. The manifold **14** extends over the entire location of the third cylinder unit **26** in the axial direction of the cylinder **20**. The manifold **14** is disposed integrally with the cylinder **20** so as to extend along the outer peripheral surface of the third cylinder unit **26** in the axial direction of the cylinder **20**. The manifold **14** is mounted to the cylinder **20** with a bolt (not shown) via the flange **26***f* of the third cylinder unit **26**. The material of the manifold **14** is an aluminum alloy.

Four pipes **16** extend from the manifold **14**. FIG. **1** shows only two of the four pipes. Each of the pipes **16** is connected to the hydraulic circuit in the manifold **14**. As described above, the cylinder **20** has four ports P. Each of the four pipes **16** is associated with a different port P and is connected to the associated port P. As a result, the fluid circuit is connected to the inner space of the cylinder **20**.

The cylinder **20** receives a piston rod **30** therein. The piston rod **30** includes a first piston unit **40** which as a whole has a cylindrical shape. The first piston unit **40** is configured such that both its outer diameter and inner diameter vary in its axially intermediate portion in an associated manner to form a step in the axially intermediate portion. Therefore, the axially A-side portion and the axially B-side portion of the first piston unit **40** have different outer diameters and different inner diameters. Specifically, in the first piston unit **40**, the outer diameter **44**L of a small diameter portion **44** constituting the B-side portion is smaller than the outer diameter **42**L of a large diameter portion **42** constituting the A-side portion. The outer diameter **44**L of the small diameter portion **44** is smaller than the inner diameter **42**P of the large diameter portion **42**. Therefore, the inner diameter of the small diameter portion **44** is also smaller than the inner diameter **42**P of the large diameter portion **42**. The boundary between the large diameter portion **42** and the small diameter portion **44** forms a step.

A first piston **46** projects outward from the outer peripheral surface of the first piston unit **40**. The first piston **46** is positioned at the end of the large diameter portion **42** on the axial direction A side. The first piston **46** extends over the entire circumference of the end of the large diameter portion **42**. In the outer peripheral surface of the first piston **46**, a groove extends over the entire circumference of the outer peripheral surface. A seal member S is mounted in the groove to block the gap between the first piston **46** and the cylinder **20**. In the first piston unit **40**, the end portion of the small diameter portion **44** on the axial direction B side forms a screw portion **44***z* having a threaded outer peripheral surface. The end of the small diameter portion **44** on the axial direction B side is closed. The wall portion closing this end has a mounting groove **44***w* formed in the inner surface thereof. As described above, the first piston unit **40** includes the first piston **46**, the large diameter portion **42** extending from the first piston **46** toward the axial direction B side, and the small diameter portion **44** extending from the large diameter portion **42** toward the axial direction B side. The end of the large diameter portion **42** on the axial direction A side forms an opening portion **42***b* through which the columnar space in the first piston unit **40** is open toward the axial direction A side.

The small diameter portion **44** of the first piston unit **40** is inserted in a cylindrical member **51** having a cylindrical shape in a second piston unit **50**. The inner diameter **51**P of the cylindrical member **51** is equal to the outer diameter **44**L of the small diameter portion **44** of the first piston unit **40**. The outer diameter **51**L of the cylindrical member **51** is equal to the inner diameter **42**P of the large diameter portion **42** of the first piston unit **40**.

A second piston **52** projects outward from the outer peripheral surface of the cylindrical member **51** of the second piston unit **50**. The second piston **52** is positioned at the end of the cylindrical member **51** on the axial direction A side. The second piston **52** extends over the entire circumference of the end of the cylindrical member **51**. The outer diameter of the second piston **52** is equal to the outer diameter of the first piston **46** of the first piston unit **40**. In the outer peripheral surface of the second piston **52**, a groove extends over the entire circumference of the outer peripheral surface. A seal member S is mounted in the groove to block the gap between the second piston **52** and the cylinder **20**.

The end surface of the cylindrical member **51** of the second piston unit **50** on the axial direction A side contacts with a step surface **40***a* at the boundary between the outer peripheral surface of the large diameter portion **42** and the outer peripheral surface of the small diameter portion **44** of the first piston unit **40**. The axial length of the cylindrical member **51** is smaller than that of the small diameter portion **44** of the first piston unit **40**. As a result, the cylindrical member **51** does not cover the entirety of the small diameter portion **44** of the first piston unit **40**, and the end portion of the small diameter portion **44** on the axial direction B side, or the screw portion **44***z*, is exposed from the cylindrical member **51**.

The screw portion **44***z*, which is exposed from the cylindrical member **51** of the second piston unit **50**, is threadably engaged with a piston end **60** for mounting an external object to the piston rod **30**. Specifically, the piston end **60** includes a coupler **62** having a columnar shape. The coupler **62** is coaxial with the first piston unit **40** and the second piston unit **50**. The outer diameter of the coupler **62** is equal to the outer diameter of the cylindrical member **51** of the second piston unit **50**. The coupler **62** has a coupling hole **62***a* formed in the end surface thereof on the axial direction A side. The inner surface of the coupling hole **62***a* is threaded. The coupling hole **62***a* is threadably engaged with the screw portion **44***z* of the first piston unit **40**. On the other hand, the end surface of the coupler **62** on the axial direction A side and radially outside the coupling hole **62***a* contacts with the end surface of the cylindrical member **51** of the second piston unit **50** on the axial direction B side. The coupler **62** and the step surface **40***a* of the first piston unit **40** compress the cylindrical member **51** interposed therebetween. A second mounting portion **64** for mounting an external object projects from the end surface of the coupler **62** on the axial direction B side. In this embodiment, the second mounting portion **64** is mounted to a flap of an aircraft.

The piston rod **30** configured as described above is received in the cylinder **20** with its central axis aligned with the central axis of the cylinder **20**. This situation is as follows. The piston rod **30** extends through a hole inside the fourth cylinder unit that constitutes the bottom portion of the cylinder **20** on the axial direction B side, and the piston rod **30** is inserted in the cylinder **20** from the axial direction B side toward the A side of the cylinder **20**. The first piston unit **40** of the piston rod **30** extends through a hole inside the second cylinder unit **24** of the cylinder **20**, so as to extend from the axial direction A side to the B side across the second cylinder unit **24**. The first piston **46** of the first piston unit **40** is positioned on the axial direction A side of the second cylinder unit **24** of the cylinder **20**. Specifically, the first piston **46** is positioned between the two ports P in the first cylinder unit **22**. A part of the large diameter portion **42** of the first piston unit **40** is positioned in the hole inside the second cylinder unit **24**. The second piston **52** of the second piston unit **50** is positioned on the axial direction B side of the second cylinder unit **24**. Specifically, the second piston **52** is positioned between the two ports in the third cylinder unit **26**. A part of the cylindrical member **51** of the second piston unit **50** is positioned in the hole inside the fourth cylinder unit **28**. The piston end **60** is positioned outside the cylinder **20**. The outer diameter of the first piston **46** is equal to the inner diameter of the main body **22***m* of the first cylinder unit **22**. The outer diameter **42**L of the large diameter portion **42** of the first piston unit **40** is equal to the inner diameter of the second cylinder unit **24**. The outer diameter of the second piston **52** is equal to the inner diameter of the third cylinder unit **26**. The outer diameter **51**L of the cylindrical member **51** of the second piston unit **50** is equal to the inner diameter of the fourth cylinder unit **28**.

A fixing member **70** having a plate-like shape is mounted to the end wall **22***a* of the first cylinder unit **22** that constitutes the bottom portion of the cylinder **20** on the axial direction A side. The fixing member **70** provided outside the cylinder **20** closes the bottom through-hole **22***b* in the end wall **22***a* of the first cylinder unit **22**. A guide member **72** having a cylindrical shape is fixed to the fixing member **70**. The guide member **72** extends through the bottom through-hole **22***b* into the cylinder **20**. In other words, the guide member **72** extends from the bottom of the cylinder **20** on the axial direction A side toward the B side. The outer diameter of the guide member **72** is equal to the diameter of the bottom through-hole **22***b*. The outer diameter **72**L of the guide member **72** is equal to the inner diameter **42**P of the large diameter portion **42** of the first piston unit **40**. Accordingly, the outer diameter **72**L of the guide member **72** is also equal to the outer diameter **51**L of the cylindrical member **51** of the second piston unit **50**. The guide member **72** is inserted in the first piston unit **40**. The guide member **72** extends to the second cylinder unit **24** with respect to the axial direction of the cylinder **20**.

A retaining groove **42***a* is formed in the inner peripheral surface of the large diameter portion **42** of the first piston unit **40** so as to extend over the entire circumference thereof. The retaining groove **42***a* is positioned in the end portion of the large diameter portion **42** on the axial direction A side. A seal member S is mounted in the retaining groove **42***a* to block the gap between the first piston unit **40** and the guide member **72**.

With the guide member **72** and the piston rod **30** received in the cylinder **20**, each of the first fluid chamber **20**A and the second fluid chamber **20**B in the cylinder **20** is partitioned into two chambers. Specifically, the first fluid chamber **20**A is partitioned into two chambers by the first piston **46** of the first piston unit **40** with respect to the axial direction of the cylinder **20**. Of these two chambers, a first partition chamber **20A1** is positioned in the axial direction A side of the cylinder **20**, and the radially inner side of the first partition chamber **20A1** is defined by the guide member **72**. A second partition chamber **20A2**, the other of the two chambers, is positioned in the axial direction B side of the cylinder **20**, and the radially inner side of the second partition chamber **20A2** is defined by the large diameter portion **42** of the first piston unit **40**. As described above, the outer diameter **72**L of the guide member **72** is smaller than the outer diameter **42**L of the large diameter portion **42**, and therefore, the cross-sectional area orthogonal to the axial direction of the cylinder **20** (hereinafter referred to as "an orthogonal cross-sectional area") related to the first partition chamber**20A1** is larger than the orthogonal cross-sectional area related to the second partition chamber **20**A2.

The second fluid chamber **20**B is partitioned into two chambers by the second piston **52** of the second piston unit **50** with respect to the axial direction of the cylinder **20**. Of these two chambers, a first partition chamber **20**B1 is positioned in the axial direction A side of the cylinder **20**, and the radially inner side of the first partition chamber **20B1** is defined by the large diameter portion **42** of the first piston unit **40**. A second partition chamber **20**B2, the other of the two chambers, is positioned in the axial direction B side of the cylinder **20**, and the radially inner side of the second partition chamber **20B2** is defined by the cylindrical member **51** of the second piston unit **50**. As described above, the outer diameter **51**L of the cylindrical member **51** of the second piston unit **50** is smaller than the outer diameter **42**L of the large diameter portion **42** of the first piston unit **40**, and therefore, the orthogonal cross-sectional area related to the second partition chamber **20**B2 is larger than the orthogonal cross-sectional area related to the first partition chamber **20B1**.

Both the radially inner side of the second partition chamber **20**A2 in the first fluid chamber **20**A and the radially inner side of the first partition chamber **20B1** in the second fluid chamber **20**B are defined by the large diameter portion **42** of the first piston unit **40**, and therefore, the partition chambers **20**A2, **20**B1 have the same orthogonal cross-sectional area. The outer diameter **72**L of the guide member **72** that defines the radially inner side of the first partition chamber **20A1** in the first fluid chamber **20**A is equal to the outer diameter **51**L of the cylindrical member **51** of the second piston unit **50** that defines the radially inner side of the second partition chamber **20**B2 in the second fluid chamber **20**B, and therefore, the partition chambers **20**A1, **20**B2 have the same orthogonal cross-sectional area.

An outer member **74** having a cylindrical shape extends from the fixing member **70** into the cylinder **20**. The outer member **74** is positioned inside the guide member **72** coaxially with the guide member **72**. An inner member **76** having a columnar shape is inserted into the outer member **74** from the axial direction B side of the cylinder **20**. The end portion of the inner member **76** on the axial direction B side is fixed to the mounting groove **44**w provided in the end portion of the first piston unit **40** on the axial direction B side. The position of the inner member **76** relative to the outer member **74** varies as the piston rod **30** reciprocates in the axial direction of the cylinder **20** in accordance with the pressures in the first fluid chamber **20**A and the second fluid chamber **20**B. The outer member **74** contains a coil with a magnetic field that varies in accordance with the position of the inner member **76**, and the variation of the magnetic field is sensed by a sensing circuit (not shown). The sensing circuit, the outer member **74**, and the inner member **76** constitute a differential transformer position sensor **73** that senses the position of the piston rod **30** by sensing the position of the inner member **76** relative to the outer member **74**.

Next, a channel system of the fluid actuator system is described. Each of the channels in the fluid actuator system is associated with a different fluid chamber of the fluid actuator, or the first fluid chamber **20**A or the second fluid chamber **20**B. First, the channel associated with the first fluid chamber **20**A is described.

Although not shown, the manifold **14** contains a tank for storing a hydraulic fluid. The tank is connected with a first feeding passage **112**. As shown in FIG. **2**, a pump **114** is installed to an intermediate portion of the first feeding passage **112**. Downstream of the pump **114** in the first feeding passage **112**, there is provided a check valve **115** for controlling backflow of the hydraulic fluid. At the opposite side to the tank, the first feeding passage **112** is connected to a first passage switching valve **120** formed of a 3-position 4-port valve.

The tank is also connected with a first discharging passage **116**. A first compensator **118** is installed to an intermediate portion of the first discharging passage **116**. The first compensator **118** stores the hydraulic fluid for replenishment. At the opposite side to the tank, the first discharging passage **116** is connected to the first passage switching valve **120**. The first compensator **118** feeds the stored hydraulic fluid toward the first passage switching valve **120** in accordance with the pressure on the first passage switching valve **120** side. When receiving a pressure at a certain or higher level from the first passage switching valve **120** side, the first compensator **118** discharges the hydraulic fluid toward the tank.

The first passage switching valve **120** is also connected with a relay passage **122** for the first partition chamber **20**A**1** and a relay passage **124** for the second partition chamber **20**A**2**, in addition to the first feeding passage **112** and the first discharging passage **116**. The first passage switching valve **120** is switched between three positions, a communication position **120**a, a disconnection position **120**b, and a reverse communication position **120**c in response to a drive signal from a controller **100** (described later), so as to control feed and discharge of the hydraulic fluid to and from the first fluid chamber **20**A. As shown in FIG. **2**, when the first passage switching valve **120** is switched to the communication position **120**a, the first feeding passage **112** is allowed to communicate with the relay passage **122** for the first partition chamber **20**A**1**, and the first discharging passage **116** is allowed to communicate with the relay passage **124** for the second partition chamber **20**A**2**. As shown in FIG. **3**, when the first passage switching valve **120** is switched to the reverse communication position **120**c, the first feeding passage **112** is allowed to communicate with the relay passage **124** for the second partition chamber **20**A**2**, and the first discharging passage **116** is allowed to communicate with the relay passage **122** for the first partition chamber **20**A**1**. As shown in FIG. **6**, when the first passage switching valve **120** is switched to the disconnection position **120**b, the first feeding passage **112** and the first discharging passage **116** are disconnected from both the relay passage **122** for the first partition chamber **20**A**1** and the relay passage **124** for the second partition chamber **20**A**2**.

As shown in FIG. **2**, the relay passage **122** for the first partition chamber **20**A**1** is connected, at the opposite side to the first passage switching valve **120**, to a first mode switching valve **126** formed of a 3-position 4-port valve. Also, the relay passage **124** for the second partition chamber **20**A**2** is connected, at the opposite side to the first passage switching valve **120**, to the first mode switching valve **126**. The first mode switching valve **126** is also connected with a communication passage **128** for the first partition chamber **20**A**1** and a communication passage **129** for the second partition chamber **20**A**2**, in addition to the relay passages **122**, **124**. Also, the communication passage **128** for the first partition chamber **20**A**1** is connected, at the opposite side to the first mode switching valve **126**, to the first partition chamber **20**A**1**. The communication passage **129** for the second partition chamber **20**A**2** is connected, at the opposite side to the first mode switching valve **126**, to the second partition chamber **20**A**2**.

The first mode switching valve **126** is switched between three positions, a communication position **126**a, a normal disconnection position **126**b, and a damping disconnection position **126**c in response to a drive signal from the controller **100** (described later), so as to control feed and discharge of the hydraulic fluid to and from the first fluid chamber **20**A. As shown in FIG. **2**, when the first mode switching valve **126** is switched to the communication position **126**a, the first mode switching valve **126** enters a normal mode. When the first mode switching valve **126** is switched to the communication position **126**a, the relay passage **122** for the first partition chamber **20**A**1** is allowed to communicate with the communication passage **128**, and the relay passage **124** for the second partition chamber **20**A**2** is allowed to communicate with the communication passage **129**. As a result, with a medium of the first passage switching valve **120**, one of the first partition chamber **20**A**1** and the second partition chamber **20**A**2** is allowed to communicate with the first feeding passage **112**, and the other is allowed to communicate with the first discharging passage **116**.

As shown in FIG. **7**, when the first mode switching valve **126** is switched to the damping disconnection position **126**c, the first mode switching valve **126** enters a damping mode. Specifically, when the first mode switching valve **126** is switched to the damping disconnection position **126**c, the communication between the relay passage **122** for the first partition chamber **20**A**1** and the communication passage **128** is disconnected, and the communication between the relay passage **124** for the second partition chamber **20**A**2** and the communication passage **129** is disconnected. Also, the communication passage **128** for the first partition chamber **20**A**1** is allowed to communicate with the communication passage **129** for the second partition chamber **20**A**2** via an orifice **126**s. Specifically, when the first mode switching valve **126** is switched to the damping disconnection position **126**c, the channel formed in the first mode switching valve **126** includes a portion having a smaller passage cross-sectional area than other portions and configured to resist the flow of the hydraulic fluid. When the first mode switching valve **126** is switched to the damping disconnection position **126**c, the first partition chamber **20A1** is allowed to communicate with the second partition chamber **20A2** with a medium of such a resistance.

As shown in FIG. **6**, when the first mode switching valve **126** is switched to the normal disconnection position **126***b*, the first mode switching valve **126** enters a free mode. When the first mode switching valve **126** is switched to the normal disconnection position **126***b*, the communication between the relay passage **122** for the first partition chamber **20A1** and the communication passage **128** is disconnected, and the communication between the relay passage **124** for the second partition chamber **20A2** and the communication passage **129** is disconnected. Also, the communication passage **128** for the first partition chamber **20A1** is allowed to communicate with the communication passage **129** for the second partition chamber **20A2** without the medium of an orifice. In other words, when the first mode switching valve **126** is switched to the normal disconnection position **126***b*, the first partition chamber **20A1** is allowed to communicate with the second partition chamber **20A2** without the medium of a resistance.

The communication passages **128**, **129**, the relay passages **122**, **124**, the first mode switching valve **126**, the first passage switching valve **120**, the first feeding passage **112**, the first discharging passage **116** constitute a first hydraulic circuit **110**. The first hydraulic circuit **110** is contained in the manifold **14**.

Next, the channel associated with the second fluid chamber **20**B is described. This channel is configured in the same manner as the first fluid chamber **20**A. Therefore, this channel is described mainly as to the connection relationship between passages and switching valves, and duplicate description will be omitted as to the details of the operation of these elements.

In the channel associated with the second fluid chamber **20**B, the tank is connected with a second feeding passage **212** and a second discharging passage **216**. As shown in FIG. **2**, a pump **214** and a check valve **215** are installed to the second feeding passage **212**. A second compensator **218** is installed to the second discharging passage **216**. The second feeding passage **212** and the second discharging passage **216** are connected to a second passage switching valve **220**. The second passage switching valve **220** is also connected with a relay passage **222** for the first partition chamber **20**B**1** and a relay passage **224** for the second partition chamber **20**B**2**. The second passage switching valve **220** is switched between a communication position **220***a*, a disconnection position **220***b*, and a reverse communication position **220***c*. The relay passage **222** for the first partition chamber **20**B**1** and the relay passage **224** for the second partition chamber **20**B**2** are connected to a second mode switching valve **226**. The second mode switching valve **226** is also connected with a communication passage **228** for the first partition chamber **20**B**1** and a communication passage **229** for the second partition chamber **20**B**2**. The communication passage **228** for the first partition chamber **20**B**1** is connected to the first partition chamber **20**B**1**, and the communication passage **229** for the second partition chamber **20**B**2** is connected to the second partition chamber **20**B**2**. The second mode switching valve **226** is switched between a communication position **226***a*, a normal disconnection position **226***b*, and a damping disconnection position **226***c*. In other words, the second mode switching valve **226** can be switched to any of the normal mode, the damping mode, and the free mode.

The communication passages **228**, **229**, the relay passages **222**, **224**, the second mode switching valve **226**, the second passage switching valve **220**, the second feeding passage **212**, the second discharging passage **216** constitute a second hydraulic circuit **210**. The second hydraulic circuit **210** is contained in the manifold **14**.

Next, a control scheme of the fluid actuator system is described. The controller **100** serving as a control unit controls the first passage switching valve **120**, the first mode switching valve **126**, the second passage switching valve **220**, and the second mode switching valve **226**. The controller **100** may be formed of one or more processors that perform various processes in accordance with computer programs (software). Alternatively, the controller **100** may be formed of one or more dedicated hardware circuits such as application-specific integrated circuits (ASICs) that perform at least a part of the various processes, or it may be formed of circuitry including a combination of such circuits. The processor includes a CPU and a memory such as a RAM or a ROM. The memory stores program codes or instructions configured to cause the CPU to perform processes. The memory, or a computer-readable medium, encompasses any kind of available medium accessible to a general-purpose or dedicated computer.

The controller **100** receives sensing signals from a plurality of pressure sensors for monitoring the pressure of the hydraulic fluid in the first hydraulic circuit **110**. The controller **100** receives sensing signals from a plurality of pressure sensors for monitoring the pressure of the hydraulic fluid in the second hydraulic circuit **210**. Further, the controller **100** receives sensing signals from the differential transformer position sensor **73**. The controller **100** calculates the moving speed of the piston rod **30** based on the sensing signals from the differential transformer position sensor **73**. Therefore, the differential transformer position sensor **73** operates as a sensing device for sensing the moving speed of the piston rod **30**. Further, the controller **100** receives signals related to a plurality of other fluid actuators mounted to the same flap as is the piston rod **30** of the fluid actuator **10**. Specifically, the controller **100** receives signals indicating which of the normal mode, the free mode, and the damping mode the mode switching valves associated with the plurality of other fluid actuators are in. The fluid actuator system includes the controller **100**, the first hydraulic circuit **110**, the second hydraulic circuit **210**, and the fluid actuator **10** described above.

Next, a description is given of the control performed by the controller **100** and the operation of the fluid actuator system according to the control. The controller **100** performs the following five switching patterns depending on whether the first hydraulic circuit **110** and the second hydraulic circuit **210** have abnormality.

<First Switching Pattern>

As shown in FIG. **2**, when none of the first hydraulic circuit **110** and the second hydraulic circuit **210** has abnormality, the controller **100** performs the first switching pattern in which the first mode switching valve **126** is switched to the communication position **126***a*, the second mode switching valve **226** is switched to the communication position **226***a*, and both are put into the normal mode. In this operation, the controller **100** switches both the first passage switching valve **120** and the second passage switching valve **220** to the respective communication positions or reverse communication positions, based on the sensing signals from the differential transformer position sensor **73**.

Specifically, when the position of the piston rod **30** is on the axial direction A side of the cylinder **20** beyond a target position, the controller **100** drives the pump **114** of the first feeding passage **112** and switches the first passage switching valve **120** to the communication position **120***a*. As a result, the first feeding passage **112** is allowed to communicate with the first partition chamber **20**A**1** of the first fluid chamber **20**A, and the first discharging passage **116** is allowed to communicate with the second partition chamber **20**A**2** of the first fluid chamber **20**A. The hydraulic fluid is fed from the first feeding passage **112** to the first partition chamber **20**A**1** of the first fluid chamber **20**A, and the hydraulic fluid is also discharged from the second partition chamber **20**A**2** of the first fluid chamber **20**A to the first discharging passage **116**. Also, the controller **100** drives the pump **214** of the second feeding passage **212** and switches the second passage switching valve **220** to the communication position **220***a*. Consequently, as with the first hydraulic circuit **110**, the hydraulic fluid is fed from the second feeding passage **212** to the first partition chamber **20**B**1** of the second fluid chamber **20**B, and the hydraulic fluid is also discharged from the second partition chamber **20**B**2** of the second fluid chamber **20**B to the second discharging passage **216**. As a result of these operations, the piston rod **30** moves toward the axial direction B side of the cylinder **20**.

Conversely, as shown in FIG. **3**, when the position of the piston rod **30** is on the axial direction B side of the cylinder **20** beyond the target position, the controller **100** drives the pump **114** of the first feeding passage **112** and switches the first passage switching valve **120** to the reverse communication position **120***c*. As a result, the first feeding passage **112** is allowed to communicate with the second partition chamber **20**A**2** of the first fluid chamber **20**A, and the first discharging passage **116** is allowed to communicate with the first partition chamber **20**A**1** of the first fluid chamber **20**A. As with the first hydraulic circuit **110**, the controller **100** also switches the second passage switching valve **220** to the reverse communication position **220***c*, such that the second feeding passage **212** is allowed to communicate with the second partition chamber **20**B**2** of the second fluid chamber **20**B, and the second discharging passage **216** is allowed to communicate with the first partition chamber **20**B**1** of the second fluid chamber **20**B. As a result of these operations, the piston rod **30** moves toward the axial direction A side of the cylinder **20**.

When the piston rod **30** reaches the target position as the first passage switching valve **120** is in the communication position **120***a*, the controller **100** stops driving the pump **114** of the first feeding passage **112**. At this time, the first compensator **118** is allowed to communicate with the second partition chamber **20**A**2** of the first fluid chamber **20**A. When the hydraulic fluid in the second partition chamber **20**A**2** is expanded by heat, the first compensator **118** stores the hydraulic fluid, and when the hydraulic fluid is contracted by heat or when the hydraulic fluid is leaking out, the first compensator **118** replenishes the second partition chamber **20**A**2** with the hydraulic fluid. The first compensator **118** operates in the same manner when the first passage switching valve **120** is in the reverse communication position **120***c*. The second compensator **218** operates in the same manner as the first compensator **118**.

<Second Switching Pattern>

As shown in FIG. **4**, when the first hydraulic circuit **110** has no abnormality and the second hydraulic circuit **210** has abnormality, the controller **100** performs the second switching pattern in which the first mode switching valve **126** is switched to the communication position **126***a*, and the first mode switching valve **126** is put into the normal mode. The controller **100** also switches the second mode switching valve **226** to the normal disconnection position **226***b* to put the second mode switching valve **226** into the free mode.

In the second switching pattern, the controller **100** switches the second passage switching valve **220** to the disconnection position **220***b*. Since the second mode switching valve **226** has been switched to the normal disconnection position **226***b*, the first partition chamber **20**B**1** of the second fluid chamber **20**B is allowed to communicate with the second partition chamber **20**B**2**. Accordingly, the hydraulic fluid can flow freely between the first partition chamber **20**B**1** and the second partition chamber **20**B**2** of the second fluid chamber **20**B in both directions.

On the other hand, as with the first switching pattern, the controller **100** switches the first passage switching valve **120** to the communication position **120***a* or the reverse communication position **120***c*, based on the sensing signals from the differential transformer position sensor **73**. When the position of the piston rod **30** is on the axial direction A side of the cylinder **20** beyond the target position, the controller **100** switches the first passage switching valve **120** to the communication position **120***a*. In this operation, the first feeding passage **112** is allowed to communicate with the first partition chamber **20**A**1** of the first fluid chamber **20**A, and the first discharging passage **116** is allowed to communicate with the second partition chamber **20**A**2** of the first fluid chamber **20**A. The hydraulic fluid is fed from the first feeding passage **112** to the first partition chamber **20**A**1** of the first fluid chamber **20**A, and the hydraulic fluid is also discharged from the second partition chamber **20**A**2** of the first fluid chamber **20**A to the first discharging passage **116**. As a result, the piston rod **30** moves toward the axial direction B side of the cylinder **20**. Conversely, when the position of the piston rod **30** is on the axial direction B side of the cylinder **20** beyond the target position, the controller **100** switches the first passage switching valve **120** to the reverse communication position **120***c*, as shown by the dashed-dotted line in FIG. **4**. In this operation, the first feeding passage **112** is allowed to communicate with the second partition chamber **20**A**2** of the first fluid chamber **20**A, and the first discharging passage **116** is allowed to communicate with the first partition chamber **20**A**1** of the first fluid chamber **20**A. The hydraulic fluid is fed from the first feeding passage **112** to the second partition chamber **20**A**2** of the first fluid chamber **20**A, and the hydraulic fluid is also discharged from the first partition chamber **20**A**1** of the first fluid chamber **20**A to the first discharging passage **116**. As a result, the piston rod **30** moves toward the axial direction A side of the cylinder **20**.

<Third Switching Pattern>

As shown in FIG. **5**, when the second hydraulic circuit **210** has no abnormality and the first hydraulic circuit **110** has abnormality, the controller **100** performs the third switching pattern in which the second mode switching valve **226** is switched to the communication position **226***a*, and the second mode switching valve **226** is put into the normal mode. The controller **100** also switches the first mode switching valve **126** to the normal disconnection position **126***b* to put the first mode switching valve **126** into the free mode.

In the third switching pattern, the controller **100** switches the first passage switching valve **120** to the disconnection position **120***b*. Since the first mode switching valve **126** has been switched to the normal disconnection position **126***b*, the first partition chamber **20**A**1** of the first fluid chamber **20**A is allowed to communicate with the second partition chamber **20**A**2**. Accordingly, the hydraulic fluid can flow freely between the first partition chamber **20**A**1** and the second partition chamber **20**A**2** of the first fluid chamber **20**A in both directions.

On the other hand, as with the first switching pattern, the controller **100** switches the second passage switching valve **220** to the communication position **220***a* or the reverse communication position **220***c*, based on the sensing signals from the differential transformer position sensor **73**. When the position of the piston rod **30** is on the axial direction A side of the cylinder **20** beyond the target position, the controller **100** switches the second passage switching valve **220** to the communication position **220***a*. In this operation, the second feeding passage **212** is allowed to communicate with the first partition chamber **20**B**1** of the second fluid chamber **20**B, and the second discharging passage **216** is allowed to communicate with the second partition chamber **20**B**2** of the second fluid chamber **20**B. The hydraulic fluid is fed from the second feeding passage **212** to the first partition chamber **20**B**1** of the second fluid chamber **20**B, and the hydraulic fluid is also discharged from the second partition chamber **20**B**2** of the second fluid chamber **20**B to the second discharging passage **216**. As a result, the piston rod **30** moves toward the axial direction B side of the cylinder **20**. Conversely, when the position of the piston rod **30** is on the axial direction B side of the cylinder **20** beyond the target position, the controller **100** switches the second passage switching valve **220** to the reverse communication position **220***c*, as shown by the dashed-dotted line in FIG. **5**. In this operation, the second feeding passage **212** is allowed to communicate with the second partition chamber **20**B**2** of the second fluid chamber **20**B, and the second discharging passage **216** is allowed to communicate with the first partition chamber **20**B**1** of the second fluid chamber **20**B. The hydraulic fluid is fed from the second feeding passage **212** to the second partition chamber **20**B**2** of the second fluid chamber **20**B, and the hydraulic fluid is also discharged from the first partition chamber **20**B**1** of the second fluid chamber **20**B to the second discharging passage **216**. As a result, the piston rod **30** moves toward the axial direction A side of the cylinder **20**.

<Fourth Switching Pattern>

As shown in FIG. **6**, the controller **100** performs the fourth switching pattern when both the first hydraulic circuit **110** and the second hydraulic circuit **210** have abnormality in the pressure of the hydraulic fluid and at least one of the other fluid actuators mounted to the same flap as is the fluid actuator **10** has a mode switching valve thereof switched to the normal mode. In the fourth switching pattern, the controller **100** switches the first mode switching valve **126** to the normal disconnection position **126***b* and switches the second mode switching valve **226** to the normal disconnection position **226***b*. That is, the controller **100** switches both the first mode switching valve **126** and the second mode switching valve **226** to the free mode. In the fourth switching pattern, the controller **100** switches the first passage switching valve **120** to the disconnection position **120***b* and switches the second passage switching valve **220** to the disconnection position **220***b*. Therefore, in the fourth switching pattern, the first partition chamber **20A1** of the first fluid chamber **20**A is allowed to communicate with the second partition chamber **20A2**, and the first partition chamber **20**B**1** of the second fluid chamber **20**B is allowed to communicate with the second partition chamber **20**B**2**. Accordingly, the hydraulic fluid can flow freely between the first partition chamber **20A1** and the second partition chamber **20A2** of the first fluid chamber **20**A in both directions. Also, the hydraulic fluid can flow freely between the first partition chamber **20**B**1** and the second partition chamber **20**B**2** of the second fluid chamber **20**B in both directions. As a result, the piston rod **30** can move under no resistance in accordance with movement of the flap being actuated by other fluid actuators.

<Fifth Switching Pattern>

As shown in FIG. **7**, the controller **100** performs the fifth switching pattern when both the first hydraulic circuit **110** and the second hydraulic circuit **210** have abnormality in the pressure of the hydraulic fluid and none of the other fluid actuators mounted to the same flap as is the fluid actuator **10** has a mode switching valve thereof switched to the normal mode. In the fifth switching pattern, the controller **100** switches the first mode switching valve **126** to the damping disconnection position **126***c* and switches the second mode switching valve **226** to the damping disconnection position **226***c*. That is, the controller **100** switches both the first mode switching valve **126** and the second mode switching valve **226** to the damping mode. In the fifth switching pattern, the controller **100** switches the first passage switching valve **120** to the disconnection position **120***b* and switches the second passage switching valve **220** to the disconnection position **220***b*. Therefore, in the fifth switching pattern, the first partition chamber **20A1** of the first fluid chamber **20**A is allowed to communicate with the second partition chamber **20A2** via the orifice **126***s*, and the first partition chamber **20**B**1** of the second fluid chamber **20**B is allowed to communicate with the second partition chamber **20**B**2** via the orifice **226***s*. Accordingly, the hydraulic fluid flows under resistance between the first partition chamber **20A1** and the second partition chamber **20A2** of the first fluid chamber **20**A in both directions. Also, the hydraulic fluid flows under resistance between the first partition chamber **20**B**1** and the second partition chamber **20**B**2** of the second fluid chamber **20**B in both directions. Therefore, the piston rod **30** moves under resistance when the flap to which it is mounted is moved. As the fifth switching pattern is continued, the movement of the flap is gradually damped.

When performing any of the first to fourth switching patterns, the controller **100** proceeds to the fifth switching pattern upon sensing that the piston rod **30** has been reciprocating at a speed equal to or greater than a prescribed speed for a period equal to or greater than a prescribed amount of time, based on the sensing result of the differential transformer position sensor **73**. That is, the controller **100** switches both the first mode switching valve **126** and the second mode switching valve **226** to the damping mode.

When the flap is oscillating at a relatively high speed during a flight of an aircraft, the flight condition of the airframe may turn instable. The above prescribed speed and the prescribed amount of time are determined previously by experiments or otherwise as values at which the flap can be stopped from oscillating before the flight condition of the airframe turns instable.

Advantageous effects of the embodiment will be now described.

(1) As to Materials of the Fluid Actuator **10**

A high rigidity is required in the vicinity of the first mounting portion **22***z* in the cylinder **20**, so as to withstand impacts acting from the airframe onto the first mounting portion **22***z*. In addition, in the cylinder **20**, a pressure produced by movement of the piston rod **30** tends to act on the wall portions positioned on the central axis of the cylinder **20** such as the end wall **22***a* of the first cylinder unit **22** and the second cylinder unit **24**. Therefore, a high rigidity is required in these portions. Because of these circumstances, in this embodiment, the first cylinder unit **22**, the second cylinder unit **24**, and the fourth cylinder unit **28** are made of a highly rigid member such as stainless steel or bronze. Stainless steel and bronze have a high specific weight. Therefore, if the cylinder **20** as a whole is made of stainless steel or bronze, the fluid actuator **10** has a large weight. With this respect, in this embodiment, the third cylinder unit **26** is made of an aluminum alloy. The third cylinder unit **26** defines the radially outer side of the second fluid chamber **20**B. Since the wall portion defining the radially outer side of the second fluid chamber **20**B receives less pressure produced by the reciprocation of the piston rod **30**, this wall portion is not required to have as high rigidity as the wall portions positioned on the axis of the cylinder **20**. In addition, since the second fluid chamber **20**B is spaced from the first mounting portion **22***z* toward the axial direction B side, the second fluid chamber **20**B is not required to have as high rigidity as the vicinity of the first mounting portion **22***z*. Therefore, the third cylinder unit **26** can be made of an aluminum alloy having a small weight. Since the third cylinder unit **26** is made of an aluminum alloy, the weight of the cylinder **20** can be reduced. Further, in this embodiment, the manifold **14** mounted to the cylinder **20** is also made of an aluminum alloy. In this way, a part of the cylinder **20** and the manifold **14** are made of an aluminum alloy, thus reducing the weight of the fluid actuator **10**.

(2) As to the Connection Between the Cylinder **20** and the Manifold **14**

(2-1) As to the Pipes **16**

In the configuration of the embodiment, the pipes **16** connect the hydraulic circuits contained in the manifold **14** to the fluid chambers in the cylinder **20**. Since the pipes **16** connect the hydraulic circuits to the fluid chambers, it is not necessary that the manifold is extended to such positions in the cylinder **20** as those of the ports P communicating with the first fluid chamber **20**A, for example. Therefore, the manifold **14** can be downsized.

(2-2) As to the Hydraulic Circuits Contained in the Manifold **14**

Since the manifold **14** is mounted integrally on the outer peripheral surface of the cylinder **20**, the manifold **14** is positioned relatively close to the first fluid chamber **20**A and the second fluid chamber **20**B. Since the hydraulic circuits, which have the passage switching valves and the mode switching valves, are contained in the manifold **14**, the pipes **16** connecting the hydraulic circuits to the fluid chambers can be short.

(3) As to the Seal Member S Mounted in the Retaining Groove **42***a* of the First Piston Unit **40**

In the fluid actuator disclosed in the '642 Patent, a fluid chamber having a columnar shape is defined within a cylinder. A guide member projects from a bottom portion of the cylinder on the one axial direction side thereof. A piston rod is inserted through another bottom portion of the cylinder on the other axial direction side thereof. The piston rod has an opening in an end portion thereof on the one axial direction side. The guide member is inserted in the piston rod through the opening. The piston rod reciprocates along the guide member. A seal member is mounted on the outer peripheral surface of the guide member to block the gap between the guide member and the piston rod. The seal member is positioned on an end portion of the guide member on the other axial direction side. In the fluid actuator disclosed in the '642 Patent, when the piston rod moves to a position at a certain distance from the seal member toward the one axial direction side of the cylinder, a gap is produced between the piston rod and the guide member on the one axial direction side beyond the seal member. Since the fluid enters such a gap, the volume of the fluid chamber enlarges by the gap and thus is different from a desired volume. The difference of the volume produces an error in the output for moving the piston rod. With this respect, in the embodiment, the seal member S is mounted in the end portion of the large diameter portion **42** on the axial direction A side. That is, the seal member S is mounted in the piston rod **30** that is a moving member, instead of the guide member **72** that is an immobilized member. Therefore, the seal member S moves along with the end portion of the large diameter portion **42** on the axial direction A side. As a result, since the seal member S moves in accordance with the position of the end portion of the large diameter portion **42** on the axial direction A side, the end portion of the large diameter portion **42** on the axial direction A side can block the gap between the first piston unit **40** and the guide member **72**, irrespective of the position of the piston rod **30** reciprocating. Since the end portion of the large diameter portion **42** on the axial direction A side can block the gap between the first piston unit **40** and the guide member **72**, the volume of the first partition chamber **20A1** in the first fluid chamber **20**A can be maintained to be substantially equal to the volume of the second partition chamber **20**B**2** in the second fluid chamber **20**B.

(4) As to the Structure of the Piston Rod **30**

In the fluid actuator disclosed in the '642 Patent, a fluid chamber is defined within a cylinder. The cylinder receives a piston rod therein. Variation of the pressure of the fluid fed into the fluid chamber causes the piston rod to reciprocate. An object to be oscillated is mounted to the piston rod. In the fluid actuator disclosed in the '642 Patent, the piston rod is required to have such a durability as to withstand repeated reciprocation with the object to be oscillated mounted thereto. By way of an example, a metal part will fatigue and lose its strength after repeated compression and tension, while it is less likely to fatigue when compression or tension is continued. In the embodiment, the cylindrical member **51** of the second piston unit **50** is compressed between the piston end **60** and the step surface **40***a* of the first piston unit **40**. Since the piston end **60** and the first piston unit **40** are threadably engaged with each other, the cylindrical member **51** is maintained to be compressed. Accordingly, the cylindrical member **51** is less likely to fatigue and thus has a reinforced fatigue strength. On the other hand, since the piston end **60** and the step surface **40***a* of the first piston unit **40** compress the first piston unit **40** interposed therebetween, the piston end **60** is pressed by the cylindrical member **51** in the direction away from the step surface **40***a* of the first piston unit **40**, or toward the axial direction B side of the cylinder **20**. The small diameter portion **44** of the first piston unit **40** is threadably engaged with the piston end **60**. As a result, the small diameter portion **44** of the first piston unit **40** is maintained to be pulled in the direction away from the step surface **40***a*. Accordingly, the small diameter portion **44** is less likely to fatigue and thus has a reinforced fatigue strength. As a result of such arrangement, the piston rod **30** as a whole has a reinforced fatigue strength.

(5) As to the Orthogonal Cross-Sectional Areas of the Fluid Chambers

When both the first mode switching valve **126** and the second mode switching valve **226** are in the free mode, the piston rod **30** moves in accordance with the movement of the flap. At a moment when the piston rod **30** moves in accordance with the movement of the flap, the piston rod **30** will move with substantially no hydraulic fluid flowing into or out of the first partition chamber **20A1** and the second partition chamber **20A2** of the first fluid chamber **20**A. Also, the piston rod **30** will move with substantially no hydraulic fluid flowing into or out of the first partition chamber **20B1** and the second partition chamber **20**B**2** of the second fluid chamber **20**B. For the first fluid chamber **20**A, the orthogonal cross-sectional area of the first partition chamber **20**A**1** is larger than that of the second partition chamber **20**A**2**. Therefore, when the first piston **46** is positioned at substantially the axial middle of the first fluid chamber **20**A, the volume of the first partition chamber **20**A**1** is larger than that of the second partition chamber **20**A**2**. In this configuration, when substantially no hydraulic fluid flows into or out of the first partition chamber **20**A**1** and the second partition chamber **20**A**2**, a force acts on the first piston **46** in the direction described as follows. The force acts from the first partition chamber **20**A**1** having the larger volume produced by the larger orthogonal cross-sectional area toward the second partition chamber **20**A**2** having the smaller volume produced by the smaller orthogonal cross-sectional area. For the second fluid chamber **20**B, the orthogonal cross-sectional area of the second partition chamber **20**B**2** is larger than that of the first partition chamber **20**B**1**. Therefore, conversely to the first fluid chamber **20**A, a force acts on the second piston **52** from the second partition chamber **20**B**2** toward the first partition chamber **20**B**1**. In this way, the piston rod **30** receives from both sides the forces acting toward the axial middle of the cylinder **20**, and therefore, the piston rod **30** is not allowed to move in any of the axial direction A side and the axial direction B side of the cylinder **20** and thus is easily retained in the position around the middle of the cylinder **20**. This is favorable in avoiding a large oscillation of the flap.

(6) As to the Hydraulic Circuits

(6-1) As to the Hydraulic Circuits Each Associated with a Different Fluid Chamber

In the fluid actuator disclosed in the '642 Patent, a fluid chamber having a columnar shape is defined within a cylinder. The fluid chamber is partitioned into two fluid chambers at the axial middle of the cylinder. The cylinder receives a piston rod therein. Two pistons project from the piston rod in the radially outward direction. One of the two pistons partitions the fluid chamber on the one axial direction side of the cylinder into two chambers. The other of the two pistons partitions the fluid chamber on the other axial direction side of the cylinder into two chambers. In the fluid actuator disclosed in the '642 Patent, the two chambers in the fluid chamber on one side are each connected to a different connection passage for feeding and discharging the hydraulic fluid. These connection passages are connected to a switching valve for switching the feeding and discharging operations of the hydraulic fluid for one and the other of the two chambers. These connection passages are branched and also connected to the two chambers in the fluid chamber on the other side. In this way, in the technique disclosed in the '642 Patent, a single switching valve switches the feeding and discharging operations of the hydraulic fluid for both of the fluid chamber on one side and the fluid chamber on the other side. In this configuration, a malfunction of the switching valve inhibits the feeding and discharging operations of the hydraulic fluid for both of the fluid chamber on one side and the fluid chamber on the other side, possibly resulting in a failure of the fluid actuator. With this respect, in the embodiment, each of the first fluid chamber **20**A and the second fluid chamber **20**B is provided with a dedicated hydraulic circuit and provided with a dedicated passage switching valve and a dedicated mode switching valve. Therefore, even when abnormality occurs in any one of the hydraulic circuits associated with the first fluid chamber **20**A and the second fluid chamber **20**B, the other hydraulic circuit can be used to feed the hydraulic fluid from a feeding passage into a fluid chamber and discharge the hydraulic fluid from a fluid chamber into a discharging passage. Accordingly, a failure of the fluid actuator **10** can be prevented.

(6-2) As to the Mode Switching Valves Each Associated with a Different Fluid Chamber

In the fluid actuator disclosed in the '642 Patent, a fluid chamber having a columnar shape is defined within a cylinder. The fluid chamber is partitioned into two fluid chambers at the axial middle of the cylinder. The cylinder receives a piston rod therein. Two pistons project from the piston rod in the radially outward direction. One of the two pistons partitions the fluid chamber on the one axial direction side of the cylinder into two chambers. The other of the two pistons partitions the fluid chamber on the other axial direction side of the cylinder into two chambers. In the fluid actuator disclosed in the '642 Patent, the two chambers in the fluid chamber on one side are each connected to a different connection passage for feeding and discharging the hydraulic fluid. These connection passages are connected to a switching valve for switching the feeding and discharging modes of the hydraulic fluid for the two chambers. This switching valve can switch between a first mode and a second mode. In the first mode, the hydraulic fluid is fed from a source of the hydraulic fluid, while in the second mode, the two chambers are connected to each other and the hydraulic fluid is fed and discharged between the two chambers. When the switching valve is switched to the second mode, the channel formed in the switching valve includes an orifice to damp the flow of the hydraulic fluid, and thus the movement of the piston rod. The above connection passages are branched and also connected to the two chambers in the fluid chamber on the other side. In this way, in the technique disclosed in the '642 Patent, a single switching valve switches the feeding and discharging modes of the hydraulic fluid for both of the fluid chamber on one side and the fluid chamber on the other side. In this configuration, a malfunction of the switching valve inhibits use of the second mode, and thus a resistance cannot be applied to the flow of the hydraulic fluid in any of the fluid chamber on one side and the fluid chamber on the other side. Therefore, the movement of the piston rod probably cannot be damped. With this respect, in the embodiment, each of the first fluid chamber **20**A and the second fluid chamber **20**B is provided with a dedicated mode switching valve. Therefore, even when abnormality occurs in any one of the mode switching valves associated with the first fluid chamber **20**A and the second fluid chamber **20**B, the other mode switching valve associated with the other can be used to perform the damping mode. Accordingly, it can be avoided that the movement of the piston rod cannot be damped.

(6-3) As to Control Related to the Damping Mode

In the fluid actuator disclosed in the '642 Patent, a fluid chamber is defined within a cylinder. The cylinder receives a piston rod therein. Variation of the pressure of the fluid fed into the fluid chamber causes the piston rod to reciprocate. In the fluid actuator disclosed in the '642 Patent, the piston rod may reciprocate in accordance with the movement of a mating object mounted to the piston rod. In some cases, it is required to damp such reciprocation of the piston rod. For example, suppose that the fluid actuator is installed in an aircraft and a flap is mounted to the piston rod. When the flap is oscillating at a relatively high speed during a flight of the aircraft, the flight condition of the airframe may turn instable. Therefore, when the oscillation of the flap at a relatively high speed has been continued for a certain amount of time, the oscillation of the flap must be stopped before the flight condition of the airframe turns instable.

With this respect, in the embodiment, when it is sensed that the piston rod **30** has been reciprocating at a speed equal to or greater than a prescribed speed for a period equal to or greater than a prescribed amount of time, both the first mode switching valve **126** and the second mode switching valve **226** are switched to the damping mode. Therefore, the reciprocation of the piston rod **30**, or the oscillation of the flap can be damped rapidly before the flight condition of the airframe turns instable.

The foregoing embodiment can be modified as described below. The above embodiment and the following modifications can be implemented in combination to the extent where they are technically consistent with each other.

The configuration of the hydraulic circuits can be modified. For example, it is possible to provide a plurality of orifices **126***s* in the channel formed in the first mode switching valve **126** when the first mode switching valve **126** is switched to the damping disconnection position **126***c*. In this case, even when one of the orifices **126***s* is no longer serving as a resistance due to breakage or otherwise, the other orifices **126***s* can apply resistance to the channel.

It is also possible to change the pair of the partition chambers to and from which the hydraulic fluid is fed and discharged via the first feeding passage **112** and the first discharging passage **116**. Along with this change, it is also possible to change the pair of the partition chambers to and from which the hydraulic fluid is fed and discharged via the second feeding passage **212** and the second discharging passage **216**. Specifically, as shown in FIG. **8**, the first partition chamber **20**A**1** of the first fluid chamber **20**A and the second partition chamber **20**B**2** of the second fluid chamber **20**B may be paired as partition chambers to and from which the hydraulic fluid is fed and discharged via the first feeding passage **112** and the first discharging passage **116**. In this case, the communication passage **128**, which is one of the communication passages connected to the first mode switching valve **126**, is connected to the first partition chamber **20**A**1** of the first fluid chamber **20**A, and the communication passage **129***a*, which is the other, is connected to the second partition chamber **20**B**2** of the second fluid chamber **20**B. In addition, the second partition chamber **20**A**2** of the first fluid chamber **20**A and the first partition chamber **20**B**1** of the second fluid chamber **20**B may be paired as partition chambers to and from which the hydraulic fluid is fed and discharged via the second feeding passage **212** and the second discharging passage **216**. Specifically, the communication passage **228**, which is one of the communication passages connected to the second mode switching valve **226**, is connected to the first partition chamber **20**B**1** of the second fluid chamber **20**B, and the communication passage **229***a*, which is the other, is connected to the second partition chamber **20**A**2** of the first fluid chamber **20**A.

When the partition chambers are paired as described above, the first passage switching valve **120** and the second passage switching valve **220** are controlled such that the communication between the first partition chamber **20**A**1** of the first fluid chamber **20**A and the first feeding passage **112** is concurrent with the communication between the first partition chamber **20**B**1** of the second fluid chamber **20**B and the second feeding passage **212**. In addition, the first passage switching valve **120** and the second passage switching valve **220** are controlled such that the communication between the second partition chamber **20**A**2** of the first fluid chamber **20**A and the second feeding passage **212** is concurrent with the communication between the second partition chamber **20**B**2** of the second fluid chamber **20**B and the first feeding passage **112**.

In the fluid actuator disclosed in the '642 Patent, a fluid chamber having a columnar shape is defined within a cylinder. The fluid chamber is partitioned into two fluid chambers at the axial middle of the cylinder. The cylinder receives a piston rod therein. Two pistons project from the piston rod in the radially outward direction. One of the two pistons partitions the fluid chamber on the one axial direction side of the cylinder into two chambers. The other of the two pistons partitions the fluid chamber on the other axial direction side of the cylinder into two chambers. In the fluid actuator disclosed in the '642 Patent, the two chambers in the fluid chamber on one side are each connected to a different connection passage for feeding and discharging the hydraulic fluid. These connection passages are connected to a switching valve for switching the feeding and discharging operations of the hydraulic fluid for one and the other of the two chambers. These connection passages are branched and also connected to the two chambers in the fluid chamber on the other side.

In the technique disclosed in the '642 Patent, a single switching valve switches the feeding and discharging operations of the hydraulic fluid for both of the fluid chamber on one side and the fluid chamber on the other side. In this configuration, a malfunction of the switching valve inhibits the feeding and discharging operations of the hydraulic fluid for both of the fluid chamber on one side and the fluid chamber on the other side, possibly resulting in a failure of the fluid actuator. To overcome this problem, it is possible to provide a plurality of switching valves. When a plurality of switching valves are provided, it is required to substantially equalize, for each switching valve, the amount of the hydraulic fluid fed via the switching valve to the amount of the hydraulic fluid discharged via the switching valve.

In the configuration shown in FIG. **8**, the first partition chamber **20**A**1** of the first fluid chamber **20**A and the second partition chamber **20**B**2** of the second fluid chamber **20**B, which constitute one of the two pairs of the partition chambers, have the same orthogonal cross-sectional area. Therefore, the amount of the hydraulic fluid fed from the first feeding passage **112** to one of these partition chambers is the same as the amount of the hydraulic fluid discharged from the other of these partition chambers to the first discharging passage **116**. Whichever partition chamber is communicated with the first discharging passage **116** to discharge the hydraulic fluid to the first discharging passage **116**, the amount of discharged hydraulic fluid is the same. Accordingly, it can be prevented that the amount of the hydraulic fluid stored in the first compensator **118** varies in accordance with the movement of the piston rod **30**. In this way, since the amount of the hydraulic fluid stored in the first compensator **118** remains substantially constant, the first compensator **118** can contain a storage chamber having a volume corresponding to the constant amount. Therefore, an optimal size can be selected for the first compensator **118** provided on the first discharging passage **116**, and the first compensator **118** need not expand.

Likewise, the second partition chamber **20**A**2** of the first fluid chamber **20**A and the first partition chamber **20**B**1** of the second fluid chamber **20**B, which constitute the other of the two pairs of the partition chambers, have the same orthogonal cross-sectional area. Accordingly, as with the above pair, it can be prevented that the amount of the hydraulic fluid stored in the second compensator **218** varies in accordance with the movement of the piston rod **30**.

Another example of modification to the hydraulic circuits is shown in FIG. **9**. In this example, the second passage switching valve **220** is omitted, and the first passage switching valve **120** is connected to both the first mode switching valve **126** and the second mode switching valve **226**. In other words, the first passage switching valve **120** is used to switch the feeding and discharging operations of the hydraulic fluid for both the first fluid chamber **20**A and the second fluid chamber **20**B. In this case, the first feeding passage **112** and the first discharging passage **116** are also used for both the first fluid chamber **20**A and the second fluid chamber **20**B. In such configuration, as shown in FIG. **9**, each of the relay passages **122**, **124** connected to the first passage switching valve **120** is branched and connected to both the first mode switching valve **126** and the second mode switching valve **226**. In such configuration, each of the first fluid chamber **20**A and the second fluid chamber **20**B is provided with a dedicated mode switching valve. Therefore, even when abnormality occurs in any one of the mode switching valves associated with the first fluid chamber **20**A and the second fluid chamber **20**B, the other mode switching valve associated with the other can be used to perform the damping mode.

Another example of modification to the hydraulic circuits is shown in FIG. **10**. In this example, the first hydraulic circuit **110** as a whole is used for both the first fluid chamber **20**A and the second fluid chamber **20**B. In other words, not only the first passage switching valve **120** but also the first mode switching valve **126** is used for switching the channels of the hydraulic fluid for both the first fluid chamber **20**A and the second fluid chamber **20**B. In this case, the communication passage **128** connecting between the first mode switching valve **126** and the first partition chamber **20**A**1** of the first fluid chamber **20**A is branched and connected to the first partition chamber **20**B**1** of the second fluid chamber **20**B. Also, the communication passage **129** connecting between the first mode switching valve **126** and the second partition chamber **20**A**2** of the first fluid chamber **20**A is branched and connected to the second partition chamber **20**B**2** of the second fluid chamber **20**B. When the first hydraulic circuit **110** is used for both fluid chambers in this manner, the manifold **14** can be downsized by the size of the second hydraulic circuit **210** omitted, making the manifold **14** more compact.

The condition related to the prescribed amount of time may be eliminated for switching the channel to the fifth switching pattern from any one of the first to fourth switching patterns based on the sensing result of the differential transformer position sensor **73**. Specifically, the first mode switching valve **126** and the second mode switching valve **226** may be switched to the damping mode immediately when it is sensed that the moving speed of the piston rod **30** is equal to or greater than the prescribed speed. For example, to damp the movement of the piston rod **30** when the piston rod **30** moves excessively fast to an abnormal degree, it is effective that the damping mode is performed with only the condition related to the prescribed speed. The value of the prescribed speed can be set appropriately in accordance with the application of the damping mode.

The sensing device for sensing the moving speed of the piston rod **30** in the fluid actuator **10** is not limited to the example in the embodiment. Another example of the sensing device is a camera for monitoring the movement of the flap. The moving speed of the piston rod **30** can be calculated based on the moving speed of the flap captured by the camera.

The configuration of the fluid actuator **10** can be modified. For example, it is possible that the outer diameter of the cylinder **20** in the axial direction A side is different from that in the axial direction B side. In the fluid actuator **10**A shown in FIG. **11**, the outer diameter of the cylinder **20** in the axial direction A side is smaller than that in the axial direction B side. In addition, the maximum value of the orthogonal cross-sectional area in the first fluid chamber **20**A, or the orthogonal cross-sectional area of the first partition chamber **20**A**1** having the larger orthogonal cross-sectional area among the two partition chambers, is smaller than the maximum value of the orthogonal cross-sectional area in the second fluid chamber **20**B, or the orthogonal cross-sectional area of the second partition chamber **20**B**2** having the larger orthogonal cross-sectional area among the two partition chambers.

In the fluid actuator disclosed in the '642 Patent, a fluid chamber having a columnar shape is defined within a cylinder. The cylinder receives a piston rod that reciprocates in the cylinder. On an end portion of the cylinder on the one axial direction side thereof, there is provided a mounting portion for mounting an external object to the cylinder. In a technique like the fluid actuator of the '642 Patent having the mounting portion provided at an end portion of the cylinder on the one axial direction side thereof, the mounting portion may be provided on the outer peripheral surface of the cylinder. In this case, at the portion of the cylinder in which the mounting portion is provided, the outer shape of the fluid actuator is larger in the radial direction by the size of the mounting portion. With this respect, in the above configuration, the maximum value of the orthogonal cross-sectional area in the first fluid chamber **20**A is smaller than the maximum value of the orthogonal cross-sectional area in the second fluid chamber **20**B. Therefore, although the first mounting portion **22***z* projects outward, the projection of the cylinder **20** in the radially outward direction can be reduced since the orthogonal cross-sectional area of the first fluid chamber **20**A is small. The expansion of the fluid actuator **10**A can be restricted at the end portion on the axial direction A side of the cylinder **20**.

It is possible that the fluid chambers and the hydraulic circuits are connected without the pipes **16**. For example, in the above configuration, the manifold **14** is disposed at the same position as the second fluid chamber **20**B with respect to the axial direction of the cylinder **20**. The interior of the manifold **14** and the second fluid chamber **20**B can be connected by aligning through-holes connecting between the inside and the outside of the manifold **14** with ports in the cylinder **20** connected to the second fluid chamber **20**B.

The extension length of the cylindrical member **51** of the second piston unit **50** can be modified as appropriate. When the extension length of the cylindrical member **51** is modified, the screw portion **44***z* can extend over the entirety of the portion of the small diameter portion **44** in the first piston unit **40** that is exposed from the cylindrical member **51**. Further, the extension length of the coupler **62** and the depth of the coupling hole **62***a* can be modified such that the piston end **60** can be threadably engaged with the entirety of the extension region of the screw portion **44***z*. When the piston end **60** can be threadably engaged with the entirety of the extension region of the screw portion **44***z*, the cylindrical member **51** of the second piston unit **50** can be fixed and compressed between the step surface **40***a* of the first piston unit **40** and the piston end **60**. As a result of modifying the extension length of the coupler **62** and the depth of the coupling hole **62***a*, the coupler **62** may reach the interior of the cylinder **20**.

The orthogonal cross-sectional areas of the partition chambers may be modified. The orthogonal cross-sectional areas can be squared with the amounts of the hydraulic fluid fed to and discharged from the partition chambers for movement of the piston rod **30**. For example, it is possible that the two partition chambers in each of the fluid chambers **20**A, **20**B have the same orthogonal cross-sectional area, or the first partition chamber **20**A**1** of the first fluid chamber **20**A and the first partition chamber **20**B**1** of the second fluid chamber **20**B have the same orthogonal cross-sectional area. The orthogonal cross-sectional areas of all the partition chambers may be different from one another. The structure of the fluid actuator **10** can be modified such that the partition chambers have the desired orthogonal cross-sectional areas.

The shape of the inner space of the cylinder **20** is not limited to the example in the above embodiment. The inner space may have a rectangular columnar shape. The projection shapes of the first piston **46** and the second piston **52** can be modified in accordance with the shape of the inner space of the cylinder **20**.

The number of the fluid chambers is not limited to the example in the above embodiment. Specifically, three or more fluid chambers may be provided.

The object to which the first mounting portion **22***z* is mounted is not limited to the example in the above embodiment. The object to which the second mounting portion **64** is mounted is also not limited to the example in the above embodiment.

The shapes of various components of the fluid actuator **10**, such as the first mounting portion **22***z* and the manifold **14**, may be modified as appropriate. The positions of the first mounting portion **22***z* and the manifold **14** may also be modified as appropriate.

The materials of the cylinder **20**, the piston rod **30**, and the manifold **14** are not limited to the examples in the above embodiment. Any material can be used if the fluid actuator **10** is not required to have a high rigidity and a light weight.

It is possible that the seal member S that blocks the gap between the piston rod **30** and the guide member **72** is mounted in the guide member **72** instead of the piston rod **30**. The seal member S can be satisfactorily mounted in the guide member **72** if the error in the volumes of the fluid chambers is not considered.

The structure of the piston rod **30** is not limited to the example in the above embodiment. It is not necessary that the second piston unit is fixed between the piston end and the first piston unit if the fatigue strength of the piston rod **30** is not considered.

It is not necessary that the first mode switching valve **126** and the second mode switching valve **226** are switched from the normal mode or the free mode to the damping mode when the moving speed of the piston rod **30** is equal to or greater than a prescribed speed.

The fluid is not limited to oils. The fluid may be a liquid other than oils, or it may be a gas.

The fluid actuator system may be applied to mechanisms other than aircrafts.

A description is hereinafter given of the technical ideas that can be grasped from the above embodiment and its modifications and the advantageous effects thereof.

A fluid actuator including: a cylinder having a columnar inner space, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space; a piston rod inserted in the cylinder toward one axial direction side from the other axial direction side, extending across the plurality of fluid chambers, and having a piston partitioning each of the plurality of fluid chambers into two chambers, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the plurality of fluid chambers; and a guide member extending from a bottom portion of the cylinder on the one axial direction side toward the other axial direction side, wherein the guide member is inserted in the piston rod, wherein a seal member is interposed between an inner surface of the piston rod and an outer surface of the guide member, and wherein the seal member is mounted in the piston rod.

As in the above configuration, the seal member is mounted in the piston rod that moves instead of the guide member fixed at a position, and therefore, the seal member moves as the piston rod moves. As a result, it can be avoided that the fluid enters the gap between the piston rod and the guide member, irrespective of the position of the piston rod reciprocating. Accordingly, it can be prevented that the volumes of the fluid chambers vary from desired volumes when the fluid enters the gap.

A fluid actuator including: a cylinder having a columnar inner space, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space; and a piston rod inserted in the cylinder toward one axial direction side from the other axial direction side, extending across the plurality of fluid chambers, and having a piston partitioning each of the plurality of fluid chambers into two chambers, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the plurality of fluid chambers, wherein the piston rod includes a piston end, a first piston unit, and a second piston unit, the piston end is used for mounting an external object to the piston rod, the first piston unit extends from the piston end toward the one axial direction side, and the second piston unit has a cylindrical shape and receives the first piston unit inserted therethrough, wherein the first piston unit includes a first piston, a large diameter portion, and a small diameter portion, the first piston partitions one of the plurality of fluid chambers on the one axial direction side into two chambers, the large diameter portion extends from the first piston toward the other axial direction side, and the small diameter portion extends from the large diameter portion toward the other axial direction side and has a smaller outer diameter than the large diameter portion, wherein the second piston unit includes a second piston and a cylindrical member, the second piston partitions another of the plurality of fluid chambers on the other axial direction side into two chambers, and the cylindrical member has a shorter axial length than the small diameter portion and receives the small diameter portion inserted therethrough, wherein the piston end is threadably engaged with an end portion of the small diameter portion on the other axial direction side, and wherein the second piston unit is fixed between the piston end and a step surface that forms a boundary between the large diameter portion and the small diameter portion of the first piston unit.

By way of an example, a metal member will fatigue and lose its strength after repeated compression and tension, while it is less likely to fatigue when compression or tension is continued. In the above configuration, the second piston unit is less likely to fatigue since it is maintained to be compressed between the piston end and the step surface of the first piston unit. Further, in the above configuration, the piston end that fixes the second piston unit in cooperation with the step surface of the first piston unit is threadably engaged with the small diameter portion of the first piston unit while being pressed by the second piston unit in the direction away from the step surface of the first piston unit.

As a result, the small diameter portion of the first piston unit is maintained to be pulled in the direction away from the step surface, and thus the small diameter portion is less likely to fatigue. As a result of such arrangement, the piston rod has a reinforced fatigue strength.

A fluid actuator including: a cylinder having a columnar inner space and a mounting portion, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space, the mounting portion being disposed on an end portion of the cylinder on one axial direction side of the inner space and configured to be mounted to an external object; and a piston rod extending across the plurality of fluid chambers and having a piston partitioning each of the plurality of fluid chambers into two chambers, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the plurality of fluid chambers, wherein a maximum value of a cross-sectional area orthogonal to the axial direction related to one of the plurality of fluid chambers at an end on the one axial direction side is smaller than a maximum value of a cross-sectional area orthogonal to the axial direction related to another of the plurality of fluid chambers.

For example, the mounting portion may project outward from an outer surface of the cylinder. Supposing that the plurality of fluid chambers have the same cross-sectional area, the outer shape of the cylinder at the portion where the mounting portion is provided is larger by the size of the mounting portion projecting from the outer surface of the cylinder. In the above configuration, the fluid chamber on the one axial direction side of the cylinder has a small cross-sectional area. Therefore, although the cylinder has a shape with a projecting outer surface, the expansion of the outer shape of the cylinder can be restricted since the cross-sectional area of the fluid chamber is small.

A fluid actuator including: a cylinder having a columnar inner space and a mounting portion, the inner space being partitioned into two fluid chambers arranged in an axial direction of the inner space, the mounting portion being disposed on an end portion of the cylinder on one axial direction side of the inner space and configured to be mounted to an external object; a piston rod extending across the two fluid chambers and having a piston partitioning each of the two fluid chambers into two chambers, the two chambers including a first partition chamber positioned on the one axial direction side and a second partition chamber positioned on the other axial direction side, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the two fluid chambers; and a manifold mounted to the cylinder and containing a hydraulic circuit of a fluid to be fed to and discharged from the two fluid chambers, wherein in the cylinder, a wall portion partitioning one of the two fluid chambers positioned on the one axial direction side is made of an iron-based alloy, and a radially outside wall portion partitioning another of the two fluid chambers positioned on the other axial direction side is made of an aluminum alloy, wherein the piston rod is made of an iron-based alloy, wherein the manifold is made of an aluminum alloy, wherein the fluid circuit and the two fluid chambers are connected via a pipe extending from the manifold to the cylinder, wherein the fluid actuator further comprises a guide member extending from a bottom portion of the cylinder on the one axial direction side toward the other axial direction side, wherein the guide member is inserted in the piston rod, wherein a seal member is interposed between an inner surface of the piston rod and an outer surface of the guide member, wherein the seal member is mounted in the piston rod, wherein the piston rod includes a piston end, a first piston unit, and a second piston unit, the piston end is used for mounting an external object to the piston rod, the first piston unit extends from the piston end toward the one axial direction side, and the second piston unit has a cylindrical shape and receives the first piston unit inserted therethrough, wherein the first piston unit includes a first piston, a large diameter portion, and a small diameter portion, the first piston partitions one of the two fluid chambers on the one axial direction side into two chambers, the large diameter portion extends from the first piston toward the other axial direction side, and the small diameter portion extends from the large diameter portion toward the other axial direction side and has a smaller outer diameter than the large diameter portion, wherein the second piston unit includes a second piston and a cylindrical member, the second piston partitions the other of the two fluid chambers on the other axial direction side into two chambers, and the cylindrical member has a shorter axial length than the small diameter portion and receives the small diameter portion inserted therethrough, wherein the piston end is threadably engaged with an end portion of the small diameter portion on the other axial direction side, and wherein the second piston unit is fixed between the piston end and a step surface that forms a boundary between the large diameter portion and the small diameter portion of the first piston unit, wherein in one of the two fluid chambers on the one axial direction side, a cross-sectional area orthogonal to the axial direction related to the first partition chamber is larger than a cross-sectional area orthogonal to the axial direction related to the second partition chamber, wherein in the other of the two fluid chambers on the other axial direction side, a cross-sectional area orthogonal to the axial direction related to the second partition chamber is larger than a cross-sectional area orthogonal to the axial direction related to the first partition chamber.

A cylinder is basically required to have rigidity, for example, in the vicinity of a mounting portion. In addition, in the cylinder, a pressure produced by movement of the piston tends to act on the wall portions positioned on the axis of the cylinder such as the wall portion partitioning adjacent fluid chambers. Therefore, a high rigidity is required in these wall portions. On the other hand, the wall portions defining the radially outer side of the fluid chambers receive less pressure produced by the movement of the piston. Therefore, the wall portions defining the radially outer side of the fluid chambers are not required to have as high a rigidity as the portions in the vicinity of the coupling portion. Such wall portions can be made of an aluminum alloy to reduce the weight of the cylinder. Further, the manifold mounted to the cylinder can also be made of an aluminum alloy, thus reducing the weight of the fluid actuator.

A fluid actuator including: a cylinder having a columnar inner space, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space; a piston rod extending across the plurality of fluid chambers and having a piston partitioning each of the plurality of fluid chambers into two chambers, the two chambers including a first partition chamber positioned on one axial direction side and a second partition chamber positioned on the other axial direction side, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the plurality of fluid chambers; and a passage switching valve for switching feeding and discharging operations for the first partition chamber and the second partition chamber of each of the plurality of fluid chambers, wherein the passage switching valve is provided for each of the plurality of fluid chambers.

In the above configuration, even supposing that a malfunction occurs in the passage switching valve associated with one fluid chamber, passage switching valves associated with the other fluid chambers can be operated. Therefore, a failure of the piston rod can be prevented.

It is possible that the fluid actuator system further includes a manifold mounted to the cylinder and containing a hydraulic circuit of a fluid to be fed to and discharged from the fluid chambers, and the manifold contains the passage switching valves.

In the above configuration, since the manifold mounted to the cylinder contains the passage switching valves, the passage switching valves can be positioned near the fluid chambers. Therefore, the channels extending from the passage switching valves to the fluid chambers can be short.

A fluid actuator including: a cylinder having a columnar inner space, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space; a piston rod extending across the plurality of fluid chambers and having a piston partitioning each of the plurality of fluid chambers into two chambers, the two chambers including a first partition chamber positioned on one axial direction side and a second partition chamber positioned on the other axial direction side, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the plurality of fluid chambers; and a mode switching valve for switching between a normal mode, a damping mode, and a free mode, wherein in the normal mode, a feeding passage for feeding a fluid is allowed to communicate with any one of the first partition chamber and the second partition chamber, and a discharging passage for discharging the fluid is allowed to communicate with the other of the first partition chamber and the second partition chamber, wherein in the damping mode, the communication between the fluid chambers and both the feeding passage and the discharging passage is disconnected, and the first partition chamber and the second partition chamber are allowed to communicate with each other via an orifice, wherein in the free mode, the communication between the fluid chambers and both the feeding passage and the discharging passage is disconnected, and the first partition chamber and the second partition chamber of each of the plurality of fluid chambers are allowed to communicate with each other without a medium of the orifice, wherein the mode switching valve is provided for each of the plurality of fluid chambers.

In the damping mode, the orifice damps the flow of the fluid between the first partition chamber and the second partition chamber of the fluid chambers in both directions. Accordingly, the movement of the piston rod is damped. Supposing that the mode switching valve has a malfunction and cannot switch to the second mode, the movement of the piston rod cannot be damped. In the above configuration, the mode switching valve is provided for each of the fluid chambers, and therefore, even supposing that a malfunction occurs in the mode switching valve associated with one fluid chamber, mode switching valves associated with the other fluid chambers can be operated. Accordingly, the mode switching valves free of a malfunction can be switched to the second mode to damp the movement of the piston rod.

A fluid actuator including: a cylinder having a columnar inner space, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space; a piston rod extending across the plurality of fluid chambers and having a piston partitioning each of the plurality of fluid chambers into two chambers, the two chambers including a first partition chamber positioned on one axial direction side and a second partition chamber positioned on the other axial direction side, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the plurality of fluid chambers; and a mode switching valve for switching between a normal mode, a damping mode, and a free mode, wherein in the normal mode, a feeding passage for feeding a fluid is allowed to communicate with any one of the first partition chamber and the second partition chamber, and a discharging passage for discharging the fluid is allowed to communicate with the other of the first partition chamber and the second partition chamber, wherein in the damping mode, the communication between the fluid chambers and both the feeding passage and the discharging passage is disconnected, and the first partition chamber and the second partition chamber of each of the plurality of fluid chambers are allowed to communicate with each other via an orifice, wherein in the free mode, the communication between the fluid chambers and both the feeding passage and the discharging passage is disconnected, and the first partition chamber and the second partition chamber of each of the plurality of fluid chambers are allowed to communicate with each other without a medium of the orifice; a controller for controlling switching of the mode switching valve; and a sensing device for sensing a moving speed of the piston rod for a predetermined amount of time, wherein the controller switches the mode switching valve from the normal mode or the free mode to the damping mode when the moving speed of the piston rod is equal to or greater than a prescribed speed.

In the above configuration, the mode switching valve is switched to the damping mode when the piston rod moves excessively fast in accordance with the movement of an external object mounted to the piston rod. Therefore, the movement of the piston rod can be damped.

A fluid actuator including: a cylinder having a columnar inner space, the inner space being partitioned into two fluid chambers arranged in an axial direction of the inner space; a piston rod extending across the two fluid chambers and having a piston partitioning each of the two fluid chambers into two chambers, the two chambers including a first partition chamber positioned on one axial direction side and a second partition chamber positioned on the other axial direction side, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the two fluid chambers; a first passage switching valve for allowing a first feeding passage for feeding a fluid to communicate with any one of the first partition chamber of the fluid chamber on the one axial direction side and the second partition chamber of the fluid chamber on the other axial direction side, and allowing a first discharging passage for discharging the fluid to communicate with the other of the first partition chamber of the fluid chamber on the one axial direction side and the second partition chamber of the fluid chamber on the other axial direction side; a first compensator disposed on an intermediate portion of the first discharging passage and configured to store the fluid and feed the fluid toward the first passage switching valve in accordance with a pressure on a first passage switching valve side; a second passage switching valve for allowing a second feeding passage for feeding the fluid to communicate with any one of the second partition chamber of the fluid chamber on the one axial direction side and the first partition chamber of the fluid chamber on the other axial direction side, and allowing a second discharging passage for discharging the fluid to communicate with the other of the second partition chamber of the fluid chamber on the one axial direction side and the first partition chamber of the fluid chamber on the other axial direction side; and a second compensator disposed on an intermediate portion of the second discharging passage and configured to store the fluid and feed the fluid toward the second passage switching valve in accordance with a pressure on a second passage switching valve side, wherein a cross-sectional area orthogonal to the axial direction related to the first partition chamber of the fluid chamber on the one axial direction side is the same as the cross-sectional area related to the second partition chamber of the fluid chamber on the other axial direction side, and wherein a cross-sectional area orthogonal to the axial direction related to the second partition chamber of the fluid chamber on the one axial direction side is the same as a cross-sectional area orthogonal to the axial direction related to the first partition chamber of the fluid chamber on the other axial direction side.

In the above configuration, since the two partition chambers connected to the first passage switching valve have the same cross-sectional area, substantially the same amount of fluids can be fed and discharged via the first passage switching valve. Therefore, it can be prevented that the amount of the fluid stored in the first compensator varies in accordance with the movement of the piston rod. The same applies to the second compensator.

In the fluid actuator system, for the two chambers of each of the fluid chambers partitioned by the piston, a cross-sectional area orthogonal to the axial direction related to the first partition chamber may be different from a cross-sectional area orthogonal to the axial direction related to the second partition chamber.

The piston rod may move in accordance with the movement of an external object mounted to the piston rod. At a moment when the piston rod moves, the piston rod will move with substantially no fluid flowing into or out of the first partition chamber and the second partition chamber. In the above configuration, the first partition chamber and the second partition chamber have different cross-sectional areas. Therefore, when the piston is positioned around the axial middle of a fluid chamber, the first partition chamber and the second partition chamber have different volumes. In this configuration, when substantially no fluid flows into or out of the first partition chamber and the second partition chamber, a force acts on the piston in the direction described as follows. The force acts from the first or second partition chamber having the larger volume produced by the larger cross-sectional area toward the other partition chamber having the smaller volume produced by the smaller cross-sectional area. For example, when in some of the plurality of fluid chambers, the first partition chamber has the larger orthogonal cross-sectional area, while in the other fluid chambers, the second partition chamber has the larger orthogonal cross-sectional area, and these fluid chambers are arranged randomly, the piston rod receives a force acting toward the one axial direction side of the cylinder and a force acting toward the other axial direction side. The piston rod receiving these forces is inhibited from moving in the axial direction. This is favorable in suppressing the movement of the piston rod.

In the fluid actuator system, there are two fluid chambers provided. In one of the two fluid chambers, the partition chamber having the larger cross-sectional area among the two partition chambers may be positioned on the one axial direction side, while in the other fluid chamber, the partition chamber having the larger cross-sectional area among the two partition chambers may be positioned on the other axial direction side.

For example, in the fluid chamber on the one axial direction side of the cylinder, the first partition chamber has a larger cross-sectional area than the second partition chamber, while in the other fluid chamber, the second partition chamber has a larger cross-sectional area than the first partition chamber. In this configuration, at a moment when the piston rod moves in accordance with the movement of an external object mounted to the piston rod, or when substantially no fluid flows into or out of the first partition chamber and the second partition chamber, the piston supposed to be positioned around the axial middle of a fluid chamber receives forces acting thereon in the directions described as follows. In the fluid chamber on the one axial direction side, a force acts from the first partition chamber toward the second partition chamber, or toward the other axial direction side of the cylinder. In the fluid chamber on the other axial direction side, a force acts from the second partition chamber toward the first partition chamber, or toward the one axial direction side of the cylinder. In other words, with respect to the axial direction of the cylinder, the piston rod receives the forces acting thereon from both its sides toward the middle of the cylinder, and therefore, the piston rod is easily retained in the position around the middle.

What is claimed is:

1. A fluid actuator comprising:

a cylinder having a columnar inner space and a mounting portion, the inner space being partitioned into a plurality of fluid chambers arranged in an axial direction of the inner space, the mounting portion being disposed on an end portion of the cylinder on one axial direction side of the inner space and configured to be mounted to an external object; and

a piston rod extending across the plurality of fluid chambers and having pistons each partitioning a respective one of the plurality of fluid chambers into two sub-chambers, the piston rod being configured to reciprocate in the axial direction in accordance with pressures in the two sub-chambers of each of the plurality of fluid chambers,

wherein in the cylinder, a first wall portion surrounding one of the plurality of fluid chambers positioned at an end on the one axial direction side is integrally and seamlessly formed with the mounting portion, the first wall portion and the mounting portion are made of an iron-based alloy, and a second wall portion surrounding another of the plurality of fluid chambers positioned on the other axial direction side beyond the one of the plurality of fluid chambers positioned at the end on the one axial direction side is made of an aluminum alloy, and

wherein the piston rod is made of an iron-based alloy.

2. The fluid actuator of claim **1**, further comprising: a manifold mounted to the cylinder and containing a hydraulic circuit of a fluid to be fed to and discharged from the sub-chambers,

wherein the manifold is made of an aluminum alloy.

3. The fluid actuator of claim **2**, wherein the hydraulic circuit and the sub-chambers are connected via respective pipes extending from the manifold to the cylinder.

4. The fluid actuator of claim **1**, wherein the two sub-chambers of the one of the plurality of fluid chambers include a first sub-chamber positioned on the one axial direction side and a second sub-chamber positioned on the other axial direction side, and

wherein a cross-sectional area orthogonal to the axial direction related to the first sub-chamber is different from a cross-sectional area orthogonal to the axial direction related to the second sub-chamber.

5. The fluid actuator of claim **4**, wherein the plurality of fluid chambers comprises two fluid chambers,

wherein in the one of the two fluid chambers, the first sub-chamber has a larger cross-sectional area, and

wherein in the other of the two fluid chambers, one of the two sub-chambers having a larger cross-sectional area is positioned on the other axial direction side.

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